

CRETACEOUS STRATIGRAPHY OF THE MT LOOKOUT AREA  
AND ITS RELATION TO THE PROPOSED REGIONAL UNCONFORMITY  
AT THE END OF THE RANGITATA OROGENY

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With 7 extra  
maps in back  
pocket.

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## ABSTRACT

This thesis examines the relationship between Torlesse-like rocks and overlying Motuan, Urutawan (Albian) rocks in the area around Mt. Lookout, central Marlborough. Previous geologists working in Marlborough have supported either a regional unconformity separating Torlesse-like from overlying rocks (e.g. Gair 1967, Laird 1980) or continuous sedimentation between Torlesse-like and overlying rocks (e.g. Wellman 1959, Lensen 1962).

Torlesse-like rocks (the Tone Fm) form the stratigraphic basement in the area and are thought to be Lower Cretaceous in age. Six Clarence aged units overlap unconformably onto the Torlesse-like basement and are incised into each other with local angular discordance. The Totara Fm (Urutawan?), the Gladstone Fm (Motuan), the Lower Winterton Fm (Motuan), the Upper Winterton Fm (Motuan), and the Castle Creek Conglomerate are a series of discrete sedimentary cycles three of which clearly show a fining upwards pattern from conglomerates and sandstones to massive mudstone. The composition, lithology, metamorphic rank, and structure of all units of Motuan or older age were studied and compared. The results from this analysis show that the overlying Motuan-Urutawan rocks are lithologically, depositionally, compositionally, and metamorphically similar to the underlying Torlesse-like rocks and that at no horizon is there a radical change.

Although there was a clear structural break between Torlesse-like and Motuan rocks in the George River, the structural distinction of Torlesse and post Torlesse rocks

in the Winterton River is subtle. These results suggest that both the Torlesse-like and the overlying Urutawan-Motuan strata represent sedimentation during the Rangitata Orogeny and that the change from Rangitata to post Rangitata conditions was evolutionary and cannot be fixed to a specific time.

## CHAPTER 1: INTRODUCTION

### AIMS AND SCOPE

The purpose of this project was to map, describe, and interpret the Cretaceous rocks around Mt. Lookout, Central Marlborough. The area of study was confined to the region S.E. of the Awatere fault, between the Tone River and Tame Stream (see Fig 1.1) with major emphasis in and around the Winterton and George Rivers.

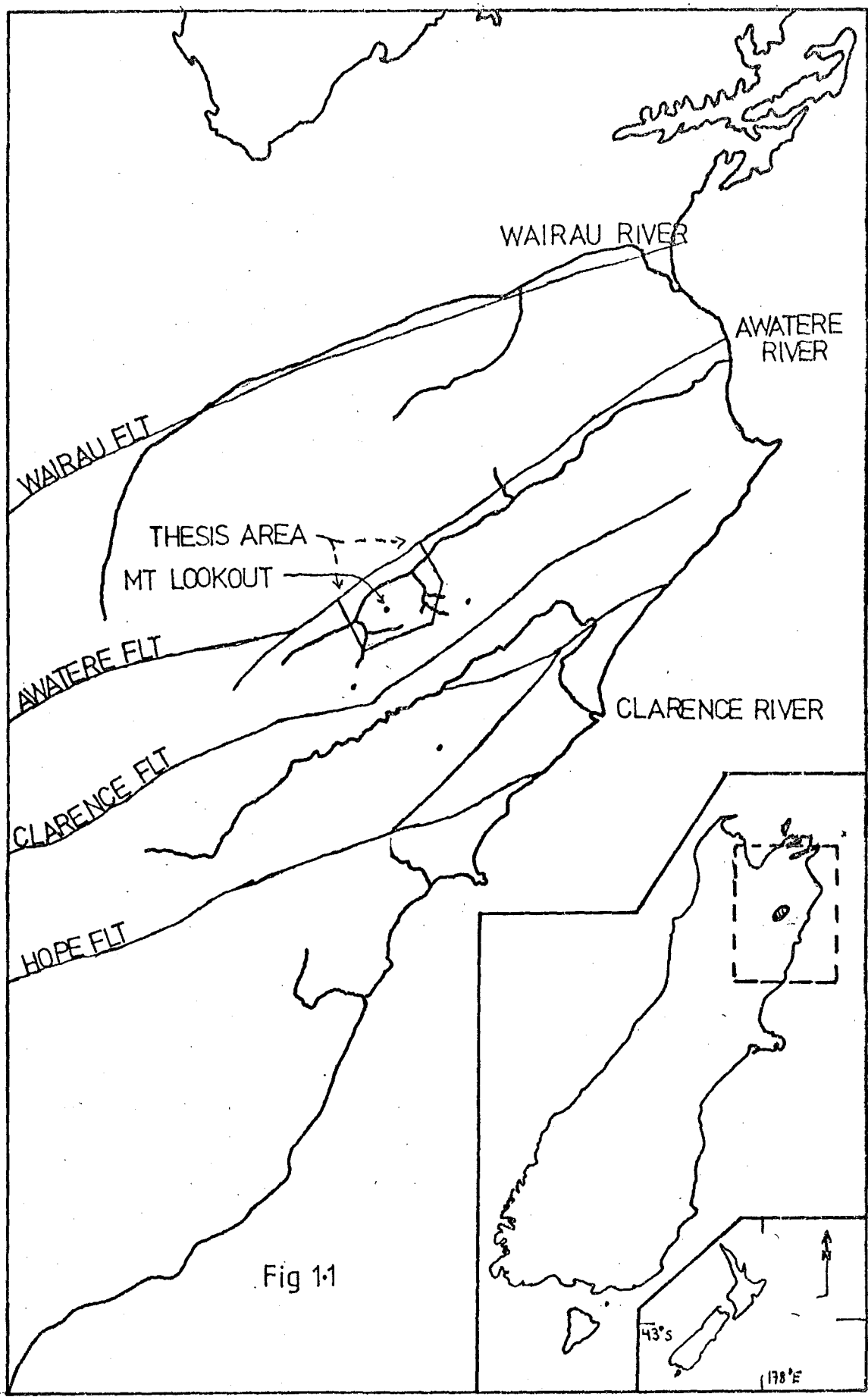
Specific objectives of the study were to determine the relationship between basement Torlesse-like rocks and overlying less deformed rocks and to examine the hypothesis that a regional unconformity divides Torlesse-like rocks from overlying strata.

### GENERAL SETTING

Mt. Lookout is a 1800m peak, 15 miles N.E. of Molesworth Station, Awatere Valley, Marlborough. Along Mt. Lookout's northern flank runs the Awatere River, which flows N.E.; the trend of the valley runs parallel to the Awatere fault (see Fig 1.1). The area of interest lies on the coners of NZMS1 S34, S35, S41, and S42. (Metric Sheets 029, P29, 030, P30).

The Awatere road provides access to Middlehurst Station (on the W. side of Mt. Lookout) and is helpful in the area between the Awatere fault and the Awatere River. South of the Awatere River, the area is accessible along the lower Winterton and George Rivers by farm tracks; however,





most of the area is accessible only by foot.

The Mt. Lookout area has a relatively dry climate and the covering vegetation is grass and scrub, the latter reaching alarming proportions in some of the streams. The terrain consists of steeply incised streams and resistant ridges and peaks, which combine to produce a rugged topography. Exposure in general is reasonable on the ridges and good in the rivers and streams.

## GEOLOGICAL SETTING

### 1. Introduction

The rocks around Mt. Lookout must be considered in two rather different contexts. In the present context, the rocks' distribution and structure are the result of the Kaikoura Orogeny. When the rocks were laid down during the Cretaceous, however, New Zealand had a different configuration and structure, related to the Rangitata Orogeny. It is therefore desirable to consider each separately.

### 2. Cretaceous Tectonic Setting

The stress regimes of New Zealand were complicated, localized, and diverse during the Cretaceous. However, in general the New Zealand structural environment evolved from a compressional regime (Rangitata Orogeny) during the Lower Cretaceous, to a tensional regime in the Upper Cretaceous (Stevens and Speden 1978, Laird 1980, Bradshaw et al 1980). In plate tectonic theory, this transition is interpreted as a shift from plate convergence (the proto Pacific subducting under Gondwana) to rifting (the separat-

ion of New Zealand from Gondwana) (Laird, 1980).

Tectonic reconstructions of New Zealand during the Cretaceous vary considerably (Kamp 1980, Wellman 1980, Bradshaw et al 1980) but agree on two important points:

- 1) That East Cape, Wairarapa, Marlborough, and the northern Chatham Rise composed the Cretaceous continental margin.

- 2) That Nelson, Fiordland, Southland, Otago, and the Campbell plateau were intracontinental areas.

These two crustal environments are fundamentally different. The continental margin rocks were welded onto proto New Zealand by the Rangitata Orogeny - a result of subduction tectonics (Bradshaw et al 1980). Consequently, the continental margin crust was thin, relatively young (Lower Cretaceous), and therefore susceptible to continental-oceanic crustal readjustment. The late Lower Cretaceous succession, therefore, is marine, depositionally and structurally complicated, and influenced by sea level changes. The intracontinental area, on the other hand, experienced the Rangitata Orogeny as a plutonic event accompanied by regional uplift. The continental crust was Precambrian to Lower Jurassic in age, and relatively stable. The Lower Cretaceous sedimentary rocks are terrestrial deposits in local basins, isolated from the Proto Pacific. Thus, the continental margin and intracontinental areas can be considered as distinct geologic provinces with tectonic chronologies which are only indirectly related.

### 3. The Problem of Orogeny and Sedimentation in the New Zealand Lower Cretaceous

There has been much interest and debate concerning the change of New Zealand from Rangitata to Post Rangitata tectonics. Recently, Gair (1967) and Laird (1980) proposed that these two tectonic regimes are separated by a major regional unconformity. The evaluation of this theory raises three classic stratigraphic problems: a) the nature of orogenics and time, b) the problem of interpreting an unconformity, and c) the accuracy of fossil dates.

#### A) Orogeny and Time

Ideas relating orogeny and time have been influenced by the views of Stille and Gilluly. Stille thought that for most of the earth's history the crust has been generally stable, although subject to regional upwarps and downwarps, this crustal stability was occasionally broken by catastrophic, world wide orogenies whose signature is a regional unconformity overlain by a basal conglomerate. This idea subsequently developed and forms the foundation for Sloss's (1963) concept of "sequences" and Chang's (1975) concept of "synthems". These two refinements of Stille's ideas were developed in intracontinental areas where lithologic units and unconformities are present over large areas. Recently, Stille's ideas have been supported by Schwan (1980) who concluded that "ages of global unconformities coincide with times of worldwide orogeny."

In contrast are the ideas of Gilluly (1949), which reflect his experience as a geologist working on the continental margin:

"It seems reasonable to take the California record at its face value, as indicating uplift in one place or another continually throughout the Cenozoic. Such movements were doubtless sporadic, like the modern faulting that causes earthquakes. They proceed now quickly, now slowly, now in this area, now in that. At each locality we have definite unconformities as local conditions changed from erosional to depositional. These unconformities mark sharply defined time gaps at this particular place. But such unconformities, when traced along strike, do not mark the identical time and indeed may change markedly in time value."

Figure 1.2 presents two simplified chronologies of South Island Cretaceous events, one representing a Stille-like interpretation, the other a Gilluly-like interpretation. Because the rocks around Mt. Lookout formed during the Rangitata/post-Rangitata transition, they should help discriminate whether the theories of Stille or Gilluly are more relevant to the New Zealand Cretaceous.

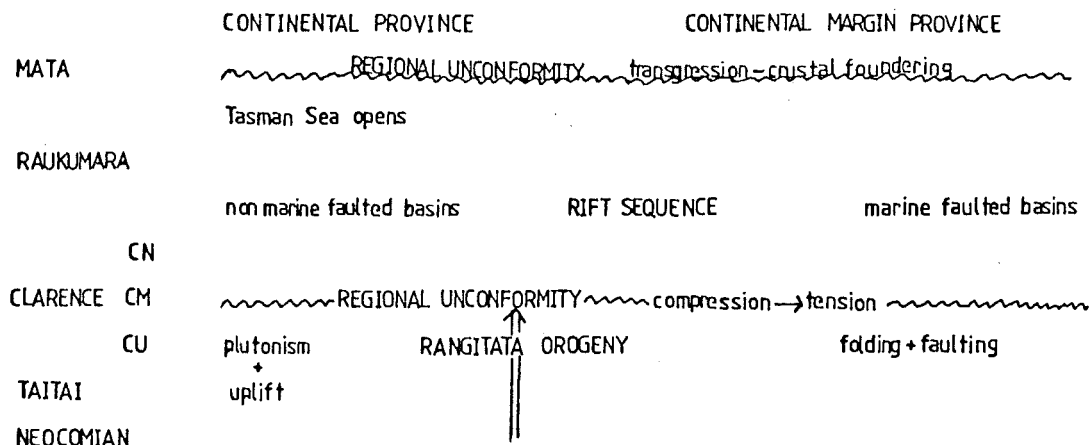
#### B) The Significance of Unconformities

Rangitata and post Rangitata regimes have in the past been distinguished by the nature of the unconformity separating them. In both continental interiors and margins, orogenies are thought to invert topography on a large scale. Thus, one would expect an unconformity separating rocks of different tectonic cycles to contain: a) a change in deformation intensity and or deformational style across the unconformity, b) a significant time break, c) a unconformity of regional extent, d) a significant break in metamorphic rank across the unconformity, e) a basal conglomerate (in the overlying sequence) composed of clasts from the underlying more deformed rocks, f) paleocurrent changes, g) changes in lithology and depositional environment, and h) changes in provenance and detrital mineral composition.

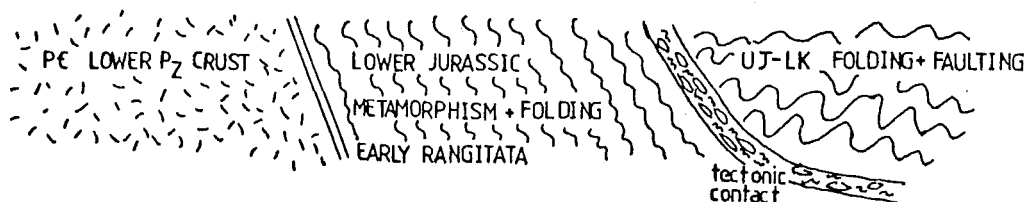
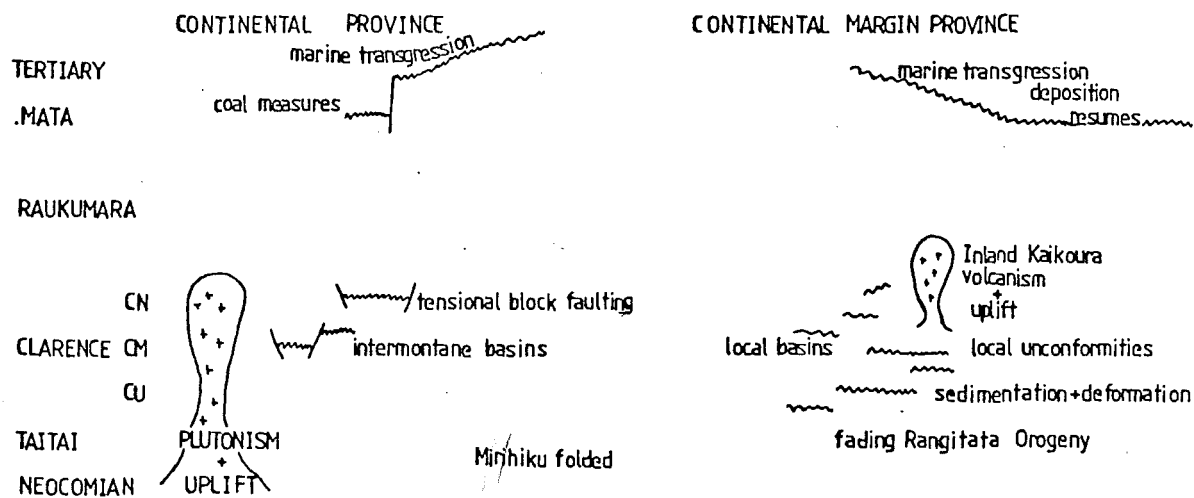
Fig 1.2

## two views of Cretaceous history (SOUTH ISLAND)

## Stillian view



## Gillulian view



If a<sup>n</sup> unconformity contained all these characteristics, one would conclude that there was a discrete break between sedimentation before deformation and sedimentation after deformation. This conclusion, however, may not apply as one moves away from the orogenic belt because orogenies produce an increase in sedimentation not a decrease. Present observations confirm that many thick, sedimentary wedges are synorogenic deposits. Thus, in evaluating an unconformity separating Rangitata and overlying rocks, there is a problem distinguishing between syn and post orogenic deposits.

In continental areas, the distinction between pre and post orogenic sedimentation may be clear because of large demonstrable time gaps separating deformation and metamorphism from sedimentation. However, as one travels basinward or to the continental margin, unconformities tend to die out and the distinction between the two units may become cryptic. A look at seismic lines across marine sections of active continental margins confirms this. Sedimentation and deformation are concurrent and migrate over time so that basins may have angular unconformities between various units, but these unconformities do not represent a change in the tectonic regime and nor do they represent an end to sedimentation in that basin (see Seeley 1979, also Van der Lingen and Pettinga, 1980).

A change in structure is one of the most common criteria used to distinguish Rangitata and post-Rangitata rocks. However, active continental margins also have a range of deformational styles (normal faulting, thrusting, folding, and sliding) all within one regime. Thus, a structural discontinuity across a unconformity in a continental margin area may represent a change in deformational style without a change

in overall tectonic regime.

In summary, the position of Marlborough on the Cretaceous Continental margin suggests there will be problems in evaluating the tectonic significance of unconformities. The following questions, therefore, must be considered in evaluating the contact between Torlesse-like and overlying Clarence aged rocks:

1. Is the contact conformable or unconformable?
2. If the contact is unconformable, then:
  - a) what are the structural differences across the unconformity?
  - b) is there a significant time break across the unconformity?
  - c) is there more than one unconformity?
  - d) is there a single unconformity of regional extent?
  - e) is there a change in metamorphic rank across the unconformity?
  - f) is there a change in depositional environment across the unconformity?
  - g) is there a change in paleocurrent direction across the unconformity?
  - h) is there a change in sediment composition across the unconformity?

#### C) Fossils and Time

The accuracy of dating is important when evaluating the significance of a unconformity. If two local unconformities have a date precision of  $\pm 5$  m yr, it is beyond the



accuracy of the dates to say the unconformities form a single surface. Gilluly (1949, 1973) has argued that even values of  $\pm 1\text{m.yr}$  would be insufficient for correlating various intra regional unconformities.

The dating of the Clarence Series is presently based on individual macrofossils whose time span is relatively long (I. Speden pers comm). For instance, the Urutawan stage was originally defined by Wellman (1959) as the zone range of Inoceramus kapuns. The Motuan stage (6 m yr long) is defined by Inoceramus ipuanus and Aucellina sp in its upper part and by Inoceramus urius and Aucellina euglypha in the lower (Wellman, 1959). Speden (1978) suggests that "the zone range of Aucellina euglypha is the best indication of the stage". Thus, the best accuracy for a Aucellina euglypha Motuan date is  $\pm 3\text{ m yr}$ . This is important because unconformities within the Motuan, although containing the same fossils above and below the unconformity, may represent a 2 million year hiatus - a significant time break. Also, units of similar lithology, structure, depositional environment, and fossil assemblage may look correlative but may in fact be of significantly different ages.

### GEOLOGIC HISTORY

The geologic history of the Mt. Lookout area can be broken down into three chapters - an active period, a passive period, and another active period.

The first chapter consists of three overlapping phases: an initial pulse of Torlesse sedimentation, interruptions in sedimentation by a phase of Rangitata diastrophism, and

resumption of sedimentation in localized basins, concurrent with deformation.

During the Rangitata orogeny, Torlesse-like rocks (the Tone Fm) were deposited by a marine distributary system, probably during the Lower Cretaceous. The depositional wedge was localized and probably rested on an older (Jurassic) previously deformed sequence. The Tone Fm was then folded and faulted by the Rangitata Orogeny - during the Lower Cretaceous.

As sites of deformation and erosion migrated, localized sedimentation was reestablished during the Albian. Continued tectonism caused submarine sliding of some of these newly deposited rocks (the Totara Fm.). Sedimentation controlled by tectonism continued, producing four fining upwards sedimentary cycles to be deposited. Each cycle (the Gladstone Fm, the Lower Winterton Fm, the Upper Winterton Fm, and the Castle Creek Conglomerate) began with a coarse basal conglomerate, fined upwards into a sandy flysch-like sequence, then graded up into a muddy flysch-like sequence, and ended with tilting and erosion. Thus, although deposited in succession during the Albian, all the cycles are unconformable upon each other.

Towards the end of Chapter 1, regional upwarping caused by igneous activity occurred followed by subsidence and the deposition of local Ngaterian marginal marine coal measures. A dyke swarm intruded the area and fed a thick sequence of alkaline basalts. These flows were erupted into a steadily subsiding basin and change from terrestrial flows at the base to pillow lavas and interbedded marine tuffs at the top.

The second chapter began after a hiatus representing the

Raukumara Series and Piripauan stage. Quiet marine glauconitic sands and micritic carbonates were deposited during the late Upper Cretaceous and lower Tertiary at Mt. Lookout and over much of Marlborough.

The third chapter comprises the Kaikoura Orogeny, which has affected Marlborough from the Miocene to the present.

## 1. Kaikoura Tectonic Setting

### a) Description

Mt. Lookout lies in the Marlborough-Wellington shear zone (Suggate et al 1978). In this zone the Alpine Fault splits into four major strike slip faults (Hope, Clarence, Awatere, Wairau) reflecting a transition from dominantly strike slip plate motion in the south (Alpine Fault) to oblique subduction in the north (Suggate et al 1978). The Awatere fault possibly predates the Alpine Fault; Suggate (in Suggate et al 1978) reports that the Awatere, Clarence, and Hope faults show a decrease in strike slip movement towards the Alpine fault and Lensen (1962) felt that the Awatere fault had been a prominent normal fault in the Miocene.

The Mt. Lookout outlier is one of a series of synclines which lie to the south of the major Marlborough faults. These synclines are the principal remnants of Cretaceous and lower Tertiary rocks which once covered Marlborough. The style of faulting and folding which characterizes Marlborough is similar to other regions having strike-slip movement - notably California. Thus, the present structure at Mt. Lookout is dominated by Kaikoura deformation and in particular

the Awatere Fault and its subsidiaries.

b) Geophysics

Seismicity around Mt. Lookout and Central Marlborough occurs at two distinct levels, each reflecting a different stress regime.

The shallow quakes ( $< 20$  km) reflect movement along the major faults (Hope, Clarence, Awatere) and first wave motion studies suggest that the displacement is strike slip and thrusting (Arabasz + Robinson, 1976). Along with movement along major faults, there is also a significant amount of scattered seismic activity - suggesting that much of the strain is taken up in the blocks between major faults (Kieckhefer, 1977). Resolution of the stress forces yields an axis of compression for central Marlborough trending N.W. to W.N.W. (Arabasz and Robinson, 1976).

The deeper focus earthquakes ( $> 21$  km) have a rather different form, oblique to the shallow trend. First wave motions indicate a dominance of normal faulting - indicating extension rather than compression. The quakes of the 21-35 km deep region are of particular interest because they appear to be related to deep quakes (33-100 km) which are interpreted as a subducting slab of oceanic crust (Arabasz and Robinson, 1976). If this is true, the continental crust beneath central Marlborough may be less than the normal  $\sim 30$  km for most continents and much thinner than most mountain ranges. More work is needed on this problem.

The gravity data in central Marlborough has an average regional field of around - 25 mgals (Bouger), compatible with crustal thicknesses of 30 km or greater. The gravity

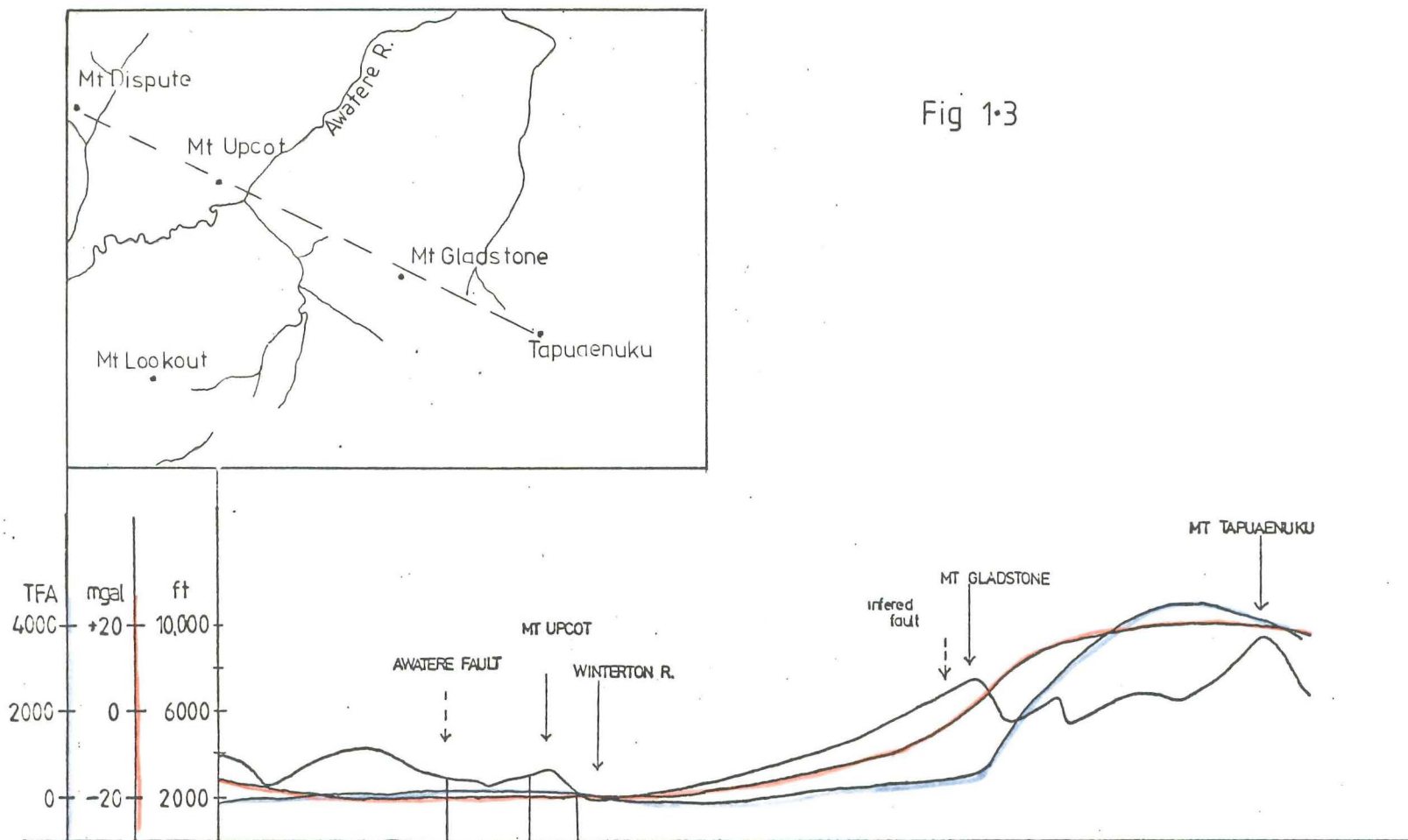


Fig 1.3

data around Mt. Lookout (as mapped on the geophysics 1:250,000 sheet, Reilly 1972) shows surprisingly little reflection of the Awatere fault. In the lower Awatere valley, Hunt (1969) did find a steep gravity gradient on the northwest side of the fault, suggesting the fault was once a normal fault, upthrown to the N.W. The lack of a gravity response in the Mt. Lookout region may reflect a sparsity of gravity stations rather than the geology. The geologic feature which dominates the gravity measurements around Mt. Lookout is the Tapuaenuku Plutonic Complex (Nicol, 1977) which has a + 20 mgals isostatic anomaly and a + 4800 total force magnetic anomaly (fig 1.3). Although the steep gravity gradient between Tapuaenuku and the Awatere R. may be due entirely to the basic igneous intrusion, the fact that the Lookout Volcanics lie 3500' below their age equivalent intrusives suggests a significant fault.

## CHAPTER 2 : STRATIGRAPHY

### INTRODUCTION

The purpose of this chapter is to describe the map units and discuss the physical and temporal nature of the contact between Torlesse-like rocks and overlying rocks.

### PREVIOUS WORK IN THE UPPER AWATERE

Geologists working along the George River have consistently found an angular unconformity separating mildly indurated and structurally simple rocks from well indurated and deformed greywackes. This relationship, however, becomes less certain in the Winterton River area.

Lensen (1962) mapped four chronostratigraphic units in the Mt. Lookout area: Taitai aged greywacke, Urutawan marine rocks, Motuan marine rocks, and Ngaterian marine and volcanic rocks. All these units, Lensen believed, were conformable upon each other. Wellman (1959) and Challis (1966) reported an angular unconformity between greywacke and Motuan rocks in the George River. Challis (1966) named these Motuan rocks the Winterton Formation.

In the Winterton River Challis (1966) recognized two true-rock units: the Gladstone Formation (CU) and the Winterton Formation (CM). The Gladstone Fm was interpreted to conformably underlie the Winterton Fm and unconformably overlie Greywacke B. Traversing the Winterton River, Gair (1967) found a "regional unconformity" separating the Winterton Fm from "pre Clarence rocks" at S35/858, 426.

THIS THESIS				CHALLIS 1966			LENSEN 1962	
Lookout Fm	Dyke Swarm	Lookout Fm	CN	Lookout Fm	Dyke Swarm	CN	Ngaterian stage	CN
Castle		Creek Conglomerate	CM?					
		Upper Winterton Fm	CM	Winterton	Fm	CM	Motuan stage	CM
		Lower Winterton Fm	CM					
		Gladstone Fm	CM		Gladstone Fm	CU	Urutawan stage	CU
		Totara Fm	CU?					
		Tone Fm	UK?	Graywacke B		J	Taitai Series	UK



Since the stratigraphic position of this unconformity was between the Winterton Fm and Gladstone Fm as mapped by Challis, Gair proposed that the area around Totara Stream was incorrectly mapped and that the Gladstone and Winterton Fms were equivalent. Speden (1977) noted Gair's unconformity but suggested that the rocks beneath it were not in fact Torlesse, but a unit between the Gladstone Fm and Greywacke B. Speden also proposed that there was an unconformity between the Gladstone and Winterton Fms.

In summary, previous workers have agreed on the stratigraphy in the George River area, but interpret the units and their relationships quite differently in the Winterton River area.

#### PROPOSALS FOR REVISION OF NOMENCLATURE

Field mapping in the course of this project has revealed inconsistencies in the stratigraphy employed by Challis. The three formations of Challis (1966), Greywacke B, Gladstone Fm, and Winterton Fm, are replaced by five formations (fig 2.1).

The name Greywacke B. is an anachronism and a new formation name (the Tone Fm) is proposed for the older rocks of "Torlesse" aspect. Challis's Gladstone Fm contains a number of unconformities and has been divided into three units, one of which retains the name Gladstone Fm (the Totara Fm, the Gladstone Fm, the Lower Winterton Fm in part). Similarly, the Winterton Fm of Challis (1966) is subdivided on the basis of unconformities into three units (the Lower Winterton Fm in part, the Upper Winterton Fm, and the Castle Creek Conglomerate). All the units mapped are purely

lithological units.

## THE TONE FORMATION (New Name)

### 1. Name and Description

The name Tone Fm. (named from the Tone R.) is proposed for the sequence of well indurated, concretionary, interbedded lithic sandstones, mudstones, and siltstones which are highly deformed and lie on the south side of the Awatere fault. This unit forms the stratigraphic basement of the area and is similar to Torlesse rocks of the Pahau subterrane (Bradshaw et al, 1980).

### 2. Type Area

The type area extends between Middelhurst Station, the Awatere River, the Tone River, and the George River. The Tone Fm is characterized by flysch-like sequences of sandstones and mudstones interrupted by thick, lenticular, massive sandstones which form resistant ridges (see fig 2.2). The unit is folded and faulted on both large and small scales so no continuous sections could be measured.

### 3. Relationship to Other Units

The Tone Fm is in fault contact (Awatere fault) with "Greywacke A" (Challis 1966) rocks in the NW, is inferred to be in fault contact with the Tapuaenuku Plutonic complex (Nicol, 1977), and is in fault contact with the Totara Fm in Totara Stream. The Tone Fm is inferred to overlies older (Jurassic?) rocks, (similar to Greywacke A) at depth. The Castle Creek Conglomerate, Upper Winterton, Gladstone, and

Lookout Fms all depositionally overlies the Tone Fm with angular unconformity.

#### 4. Distribution and Thickness

The Tone Fm lies on the south side of the Awatere River from the Jordon River (Awapiri Station) to at least Weka Brook (Muller Station) and perhaps as far as Molesworth Station. Landsat photographs suggest that towards the south, the Tone Fm is separated by a fault from the crest of the Inland Kaikoura Range. Due to structural complexities, the thickness of the Tone Fm was impossible to measure, but the unit probably exceeds 3000m in thickness.

#### 5. Age and Interpretation

Although the Tone Fm has been mapped by Lensen (1962) as Taitai Series, there are no fossil localities noted in the Mt. Lookout area, nor were there any fossils discovered during this study. In the Middle Awatere a specimen of Inoceramus sp ex gr kapuus-ipuanus was found (Speden 1977) 1.2 km south of the Penk River in rocks mapped by Allen (1962) as Greywacke B. Since there appears to be a unit between the Tone Fm and the Penk River olistostrome (see Chapter 7), it is not certain whether this fossil is from the Tone Fm. Challis (1966) regarded the Tone Fm as Jurassic based on induration. The rocks of the Tone Fm have very similar compositions and provenience to Neocomian-Albian aged rocks in the Pahau River area (Raine 1977, Andrews 1980).

The Tone Fm represents deposits of a submarine distributary system and probably lies at the proximal end of a sediment wedge (see Chapter 3).

Fig. 2.2

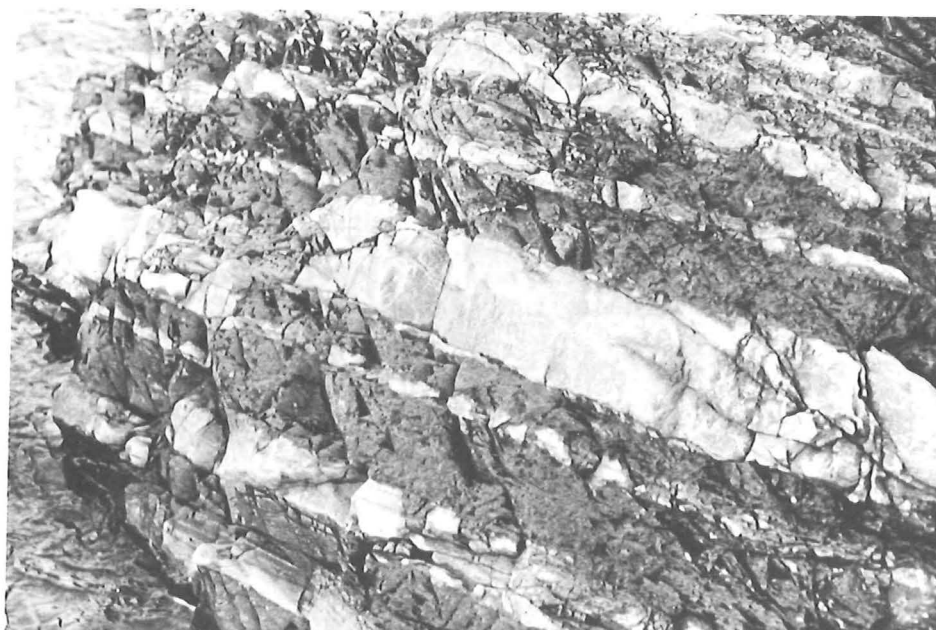
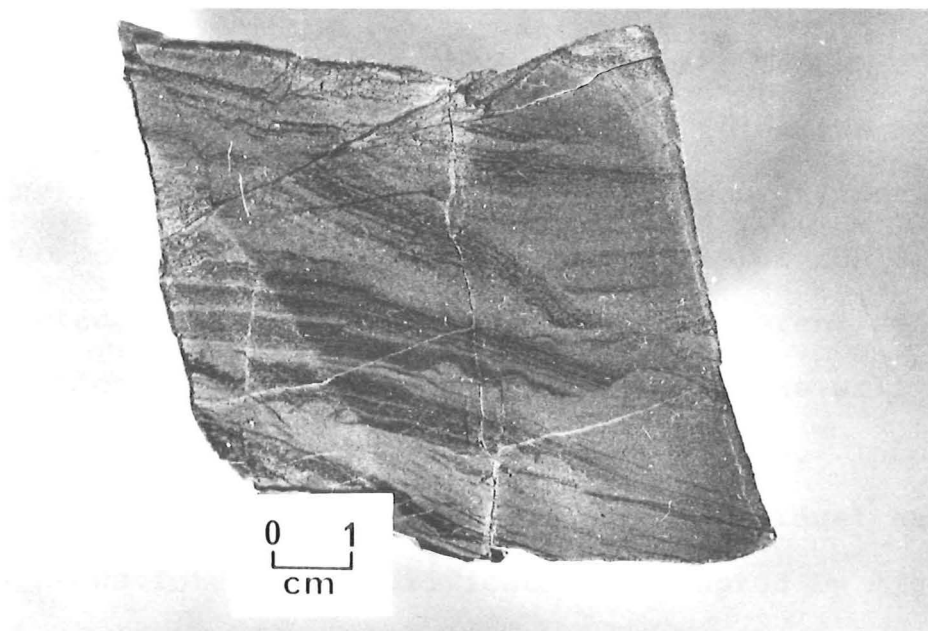
Thick sandstones of the Tone Fm,  
note how they tend to form ridges

Fig. 2.3

TOTARA FM: internal bed disruption  
by remobilization and microfaults

Fig 2.4

GLADSTONE FM: Local, well developed  
cleavage in pelitic units.



## THE TOTARA FM (New Name)

### 1. Name and Description

The Totara Formation (named from Totara Stream) is proposed for a flysch-like sequence of well indurated, alternating sandstones, mudstones, and siltstones which have been intensely deformed so that locally the original continuity of the strata has been destroyed.

Characteristically, the Totara Fm is tightly folded or broken up into small blocks; consequently, the unit lacks a coherent structure. Within the small blocks the sandstone beds are boudinaged and well sheared; the folds are small scale (metres across), asymmetric, tight, and discontinuous. Mud is commonly squeezed out from the hinges of the folds and injected up small faults or in between coherent sandstone-mudstone blocks. Blocks several metres long as well as individual sand beds show pull apart structures. Intense disruption also occurs internally within individual sandstones. Fig 2.3 shows internal stratification disrupted by micro-faulting and plastic remobilization of the sand.

The dominant lithologies are sand rich or mud rich flysch-like units. The sandstones are fine to very fine grained, moderately well to well sorted, complexly cemented (see Chapter 5), feldspathic, lithic arenites. Zeolite, calcite, and clay filled veins and occur macro and microscopically. The sandstones are structureless and parallel laminated; the tops and bottoms of the beds are sharp, but this is at least partly a consequence of deformation.

## 2. Type Area and Relation to Other Units

The type area lies in Totara Stream where the Totara Fm is faulted against the Tone Fm in the SE and overlain by the basal conglomerate of the Gladstone Fm near the mouth of Totara Str. (S35/865, 427). In the Winterton River, the contact of the Gladstone on the Totara represents a Cretaceous slump. Because of the structural complexity, no reference section could be measured.

## 3. Distribution and Thickness

The Totara Fm is recognized with certainty only in the area around Totara Str. and the adjacent Winterton River; the outcrop is thought to be controlled by faulting. Since no stratigraphic succession can be readily measured, the true thickness is unknown, but possibly exceeds 500m.

## 4. Age

No fossils have been discovered in the Totara Fm. However, a similar unit in the Middle Awatere (lower Penk River) yielded Inoceramus kapuus (Allen 1962) which suggests a Clarence Series age (Speden 1977). The Totara Fm has sandstones and mudstones of almost identical composition with the Gladstone Fm (see Chapter 4) and so is inferred to have a similar age (Clarence).

## 5. Interpretation

The intense disruption occurred when the Totara Fm was no more than partially lithified; this deformation is

interpreted as caused in part by submarine slumping or sliding. Modern submarine slumping and sliding is common off large deltas, but this type of mass movement does not destroy the bedding fabric of the sliding block, for internal seismic reflectors are continuous (Walker and Massingill, 1970). Therefore the deformation may be tectonic in part. Flysch-like units may originate from a variety of environments from deltas to submarine fans. The allochthonous nature of the Totara Fm, the internal disruption, and the lack of fossils makes determination of the depositional environment difficult. However the very fact that the Totara Fm is allochthonous suggests deposition on or near a metastable slope rather than on a platform.

#### THE GLADSTONE FM (Redefined Unit)

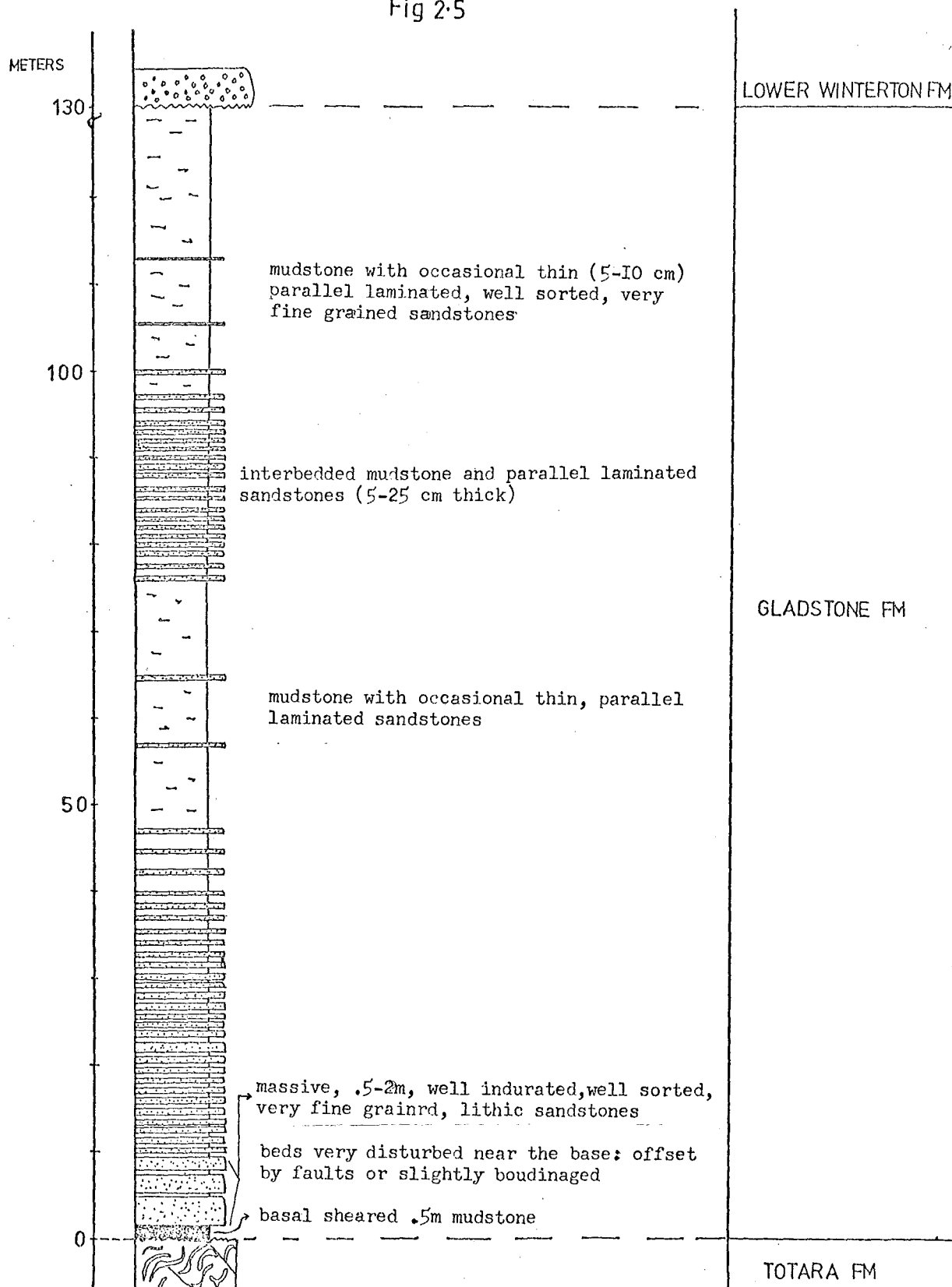
##### 1. Name and Description

The name Gladstone Formation (named from Gladstone Str.) is retained from the nomenclature of Challis (1966) but the unit has been redefined and restricted. The Gladstone Formation comprises folded and tilted, moderately to well indurated, non fossiliferous strata of alternating sandstones, siltstones, mudstones, and localized conglomerates.

The sandstones are locally carbonaceous, moderately well to well sorted, fine to very fine grained, complexly cemented, feldspathic, lithic arenites. Sedimentary structures include parallel lamination, cross lamination, ripples, massive beds, sole marks, and current lineations. Post sedimentary features include the local development of cleavage (fig 2.4), joints, load structures, convolute laminations,



Fig 2.5



microfaults, solution veins, zeolite veins, and calcite veins. The mudstones and siltstones are interlaminated or structureless. The pebble to small boulder sized conglomerates are matrix and clast supported, internally structureless or bedded, and contain sandy or muddy matrix. Overall, the Gladstone Fm fines upward. Sandstones are thickest near the base (2m) and generally range from 5-25 cm thick. The formation is relatively sand rich to the SW and mud rich to the NE.

## 2. Type Area

The type area lies between Gladstone Cr. and Totara Str. The strata are in place and steeply tilted ( $50-70^{\circ}$ ), but exposure is limited by scrub and float. Figure 2.5 is a reference section measured along a ridge top at S35/867, 427; the sequence fines upward and is bounded by unconformities. Although the basal unit is mudstone, the lowest 20 m of the Gladstone Fm is sand rich and contains massive sandstones ranging from .5 to 2 meters thick. This unit changes into an evenly bedded sequence of alternating sandstones and mudstones which becomes mud rich and then evenly bedded once again. The uppermost 30 meters is mud dominated with occasional thin (5-10 cm thick) beds of laminated sandstone.

The basal mudstone is around .5 m thick but pinches and swells considerably; the thick sandstones overlying this mudstone are also disturbed, but the unit is structurally coherent. The Gladstone unconformably overlies boudinaged and tightly folded sandstones and mudstones of the Totara Fm at S35/867, 427, but the underlying unit is uncertain at S35/867, 437. The Gladstone is unconformably overlain

in the type area by the Lower Winterton Fm.

### 3. Relationship to Other Units

The Gladstone Fm depositionally and unconformably overlies the Totara Fm in the type area, and similarly overlies the Tone Fm at S35/867, 459. However, the Gladstone has a slump contact (of Cretaceous age) on the Totara Fm in the Winterton River at S35/861, 417. Where allochthonous, the Gladstone formation is folded with a well developed cleavage (fig 2.4) and can easily be confused with the Tone Fm. The strike of the slump or slide contact on the Totara Fm at S35/861, 417 (fig 2.6) is almost perpendicular to the strike of the Gladstone Fm, dips  $32^{\circ}$  to the NW, and has a basal sheared zone of sandstone chunks floating in mudstone. The Gladstone Fm is unconformably overlain by the Lower Winterton Fm in the middle and lower Winterton River and by the Upper Winterton Fm in the uppermost Winterton River.

### 4. Distribution and Thickness

The Gladstone Fm. crops out only in the Winterton River area. Because of subsequent faulting and erosion, the thicknesses are variable; in the type area the section is between 130-150 m thick, in the allochthonous section the formation appears to be thicker.

### 5. Age

Field identification by I. Speden of Aucellina euglypha Woods in Gladstone mudstone cropping out at S35/853, 447 dates at least the upper part of the Gladstone Fm as Motuan. No other fossils have been found.

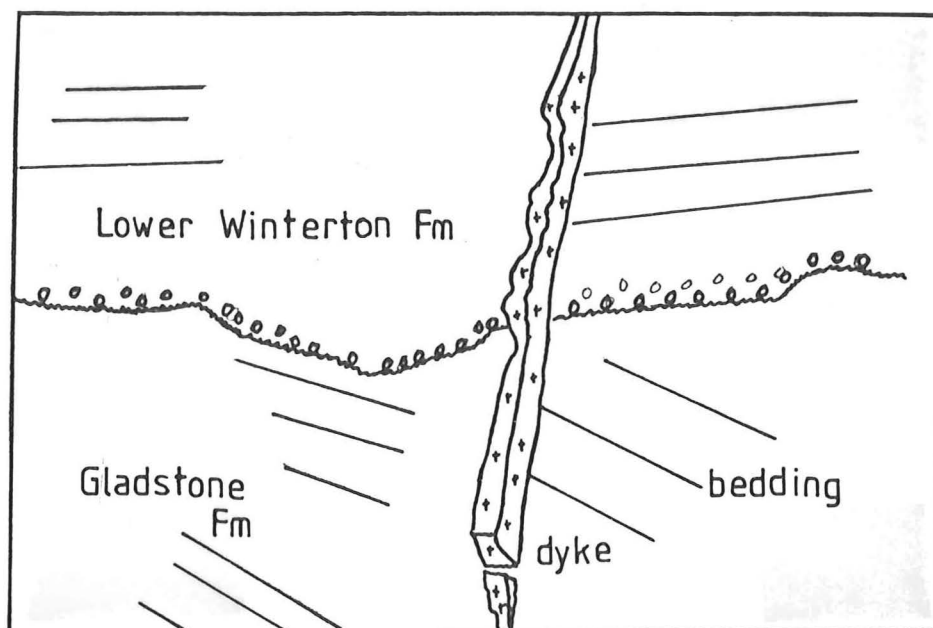
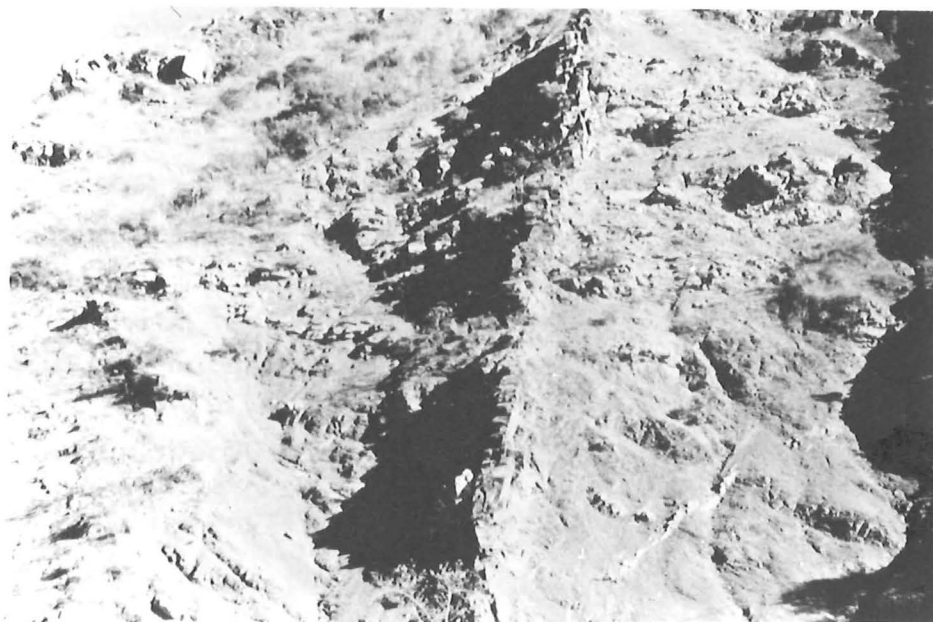
Fig. 2.6

Sand rich Gladstone Fm discordantly overlying the Totara Fm; contact is inferred to be a slump/slide; note how muddy and highly deformed the Totara Fm is.

Fig. 2.8

Lower Winterton Fm Conglomerate unconformably overlying steeply tilted, mud rich facies of the Gladstone Fm; note dyke at centre.

SKETCH OF FIG. 2.8



## 6. Interpretation

The Gladstone Fm is a fining upward, flysch-like sequence which generally resembles the fining upward character of the overlying Lower Winterton Fm and Upper Winterton Fm. This repetition of sedimentation style suggests the Gladstone Fm is one in a series of sedimentary cycles. The Gladstone Fm lacks distributary like sequences thought to be indicative of submarine fans (Walker, 1979) and more closely resembles marine flysch-like deposits in localized basins (Van der Lingen and Pettinger 1980). The partially allochthonous character of the Gladstone suggests deposition on a slope rather than a platform.

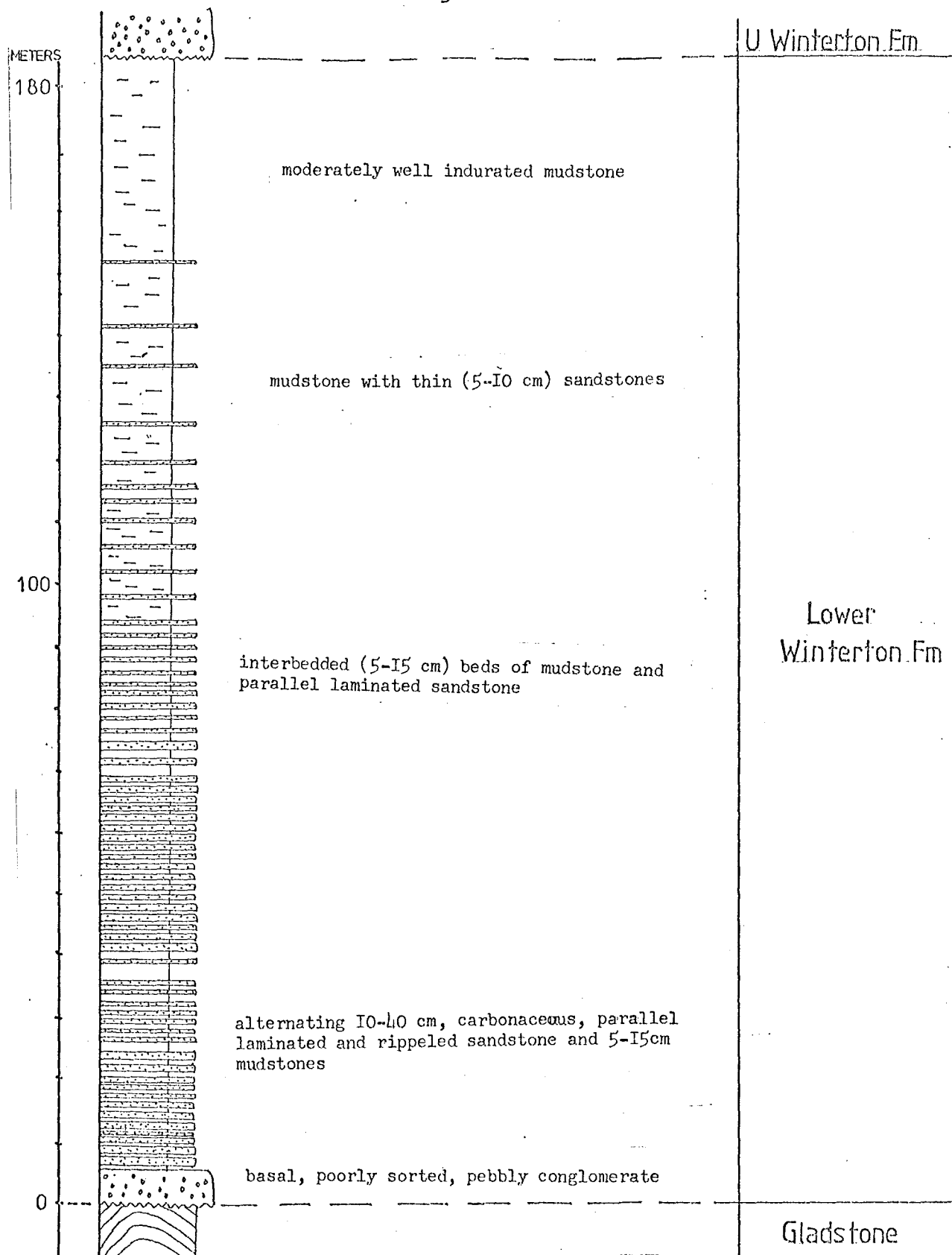
### THE LOWER WINTERTON FM (New Name)

#### 1. Name and Description

The name Lower Winterton Formation (named for the Winterton River) is proposed for a sequence of moderately indurated, non fossiliferous, mildly deformed, interbedded sandstones, mudstones, siltstones, and conglomerates.

The sandstones are moderately to well sorted, fine to very fine grained, feldspar and zeolite cemented, feldspathic, lithic, and occasionally carbonaceous arenites. Sand beds are massive, graded, parallel and cross laminated, and rippled with intermittent sole marks and current lineations. Post sedimentary features included microfractures, load features, convolute lamination, zeolite and calcite veins. Mudstones and siltstones were interlaminated or structureless. Conglomerates appear through most of the

Fig 2-7



section and are common in the lower half; bed types varied from thick (20 m<sup>+</sup>), massive, clast supported, boulder to pebble sized, muddy or sandy matrix conglomerates in the basal section to thin (.5 m) matrix supported, pebbly to granule sized, massive or bedded conglomerates in the upper sections of the formation.

The Lower Winterton Fm is grossly a fining upward sequence of basal conglomerates grading up to sandstones and finally into mudstone. The unit thickens from the SW to the NE and is structurally simple.

## 2. Type Area

The type area lies directly east of Mt. Winterton and above the Winterton River. It is in some ways an unsatisfactory type area because the sequence is thin and relatively fine grained compared to the section to the east. The thicker sequence was not chosen as the type area because the top of the section is faulted out. Figure 2.7 shows the reference section for the Lower Winterton Fm measured along a ridge at S35/857, 414. The basal deposit consists of 3 metres of pebble sized, structureless, matrix and clast supported, muddy and sandy matrix conglomerate; this rests unconformably on folded Gladstone sandstones and mudstones. The conglomerate is followed by a flysch-like sequence of relatively thick carbonaceous sands (10-40 cm thick) interbedded with thinner mudstones (5-15 cm thick). This fades upwards into a mud dominated sequence with thin (5-15 cm) sandstones; the final 10 meters is mostly mudstone with thin laminated silt beds. The unit is unconformably but concordantly overlain by the basal conglomerate of the Upper Winterton Fm.



### 3. Relationship to Other Units

As shown in fig 2.8, the basal conglomerate of the Lower Winterton Fm. overlies the Gladstone Fm with angular discordance at S35/859, 429. However, down the Winterton River at S35/853, 447 the base of the Lower Winterton Fm is sandstone and overlies the massive mudstone of the Gladstone Fm without apparent discordance (fig 2.9). Intense faulting of the contact makes it difficult to follow in the area between the Winterton River and Kicking Horse Creek. In general the contact between the Lower Winterton Fm and the Gladstone Fm is sharp and sinuous but at several localities (S35/866, 428 and S35/859, 429) there are patches where the contact is ill defined and well rounded pebbles appear in the Gladstone mudstone a few centemeters below the contact. This suggests that the Gladstone Fm was unlithified during the deposition of the Lower Winterton and that pebbles sank into Gladstone Fm mud.

The Lower Winterton is everywhere overlain and truncated to the SW by the Upper Winterton Fm.

### 4. Distribution and Thickness

The Lower Winterton Fm. crops out only in the middle and upper Winterton River area and thickens considerably from the SW to the NE. The basal contact in the Winterton River at S35/859, 429 reappears on the ridge above Totara Str. at S35/865, 428. The offset is linear and the formation is much thicker to the east (500 m<sup>+</sup>) of this offset than to the west (150-200 m). The offset is therefore interpreted to be a synsedimentary fault which trends roughly NW-SE and is named the Totara Fault.

Both the Gladstone and Lower Winterton Fms. are missing from the Awatere River section at Dead Man's Rock (S35/857, 485) which is only two miles away from where both these formations are thickly preserved around Thorn Peak. These units were either not deposited at Dead Man's Rock or were eroded away before the deposition of the Upper Winterton Fm.

### 5. Age

Wellman (in Challis, 1966) reported an incomplete specimen of Pseudolima sp. which he interpreted as Urutawan in rocks mapped here as Lower Winterton Fm. Gair (1967) found a Motuan fossil Inoceramus ipuanus in the Lower Winterton at S35/707, 861. The presence of Aucellina euglypha Woods in the underlying Gladstone and the overlying Upper Winterton Fm suggests that the Lower Winterton Fm is entirely Motuan in age.

### 6. Interpretation

The Lower Winterton Fm is a marine, fining upward sequence whose deposition was concurrent with faulting. The unit has no features diagnostic of a large submarine distributary system and, like the Gladstone Fm, is interpreted as a small basin fill. The presence of an incised channel (see Chapter 3) at the base, the inplace nature of the unit, and the structural simplicity suggests the Lower Winterton Fm was deposited on a more stable site than the underlying Gladstone Fm. The contact between the Lower Winterton and Gladstone Fm suggests a short time break between these two units.

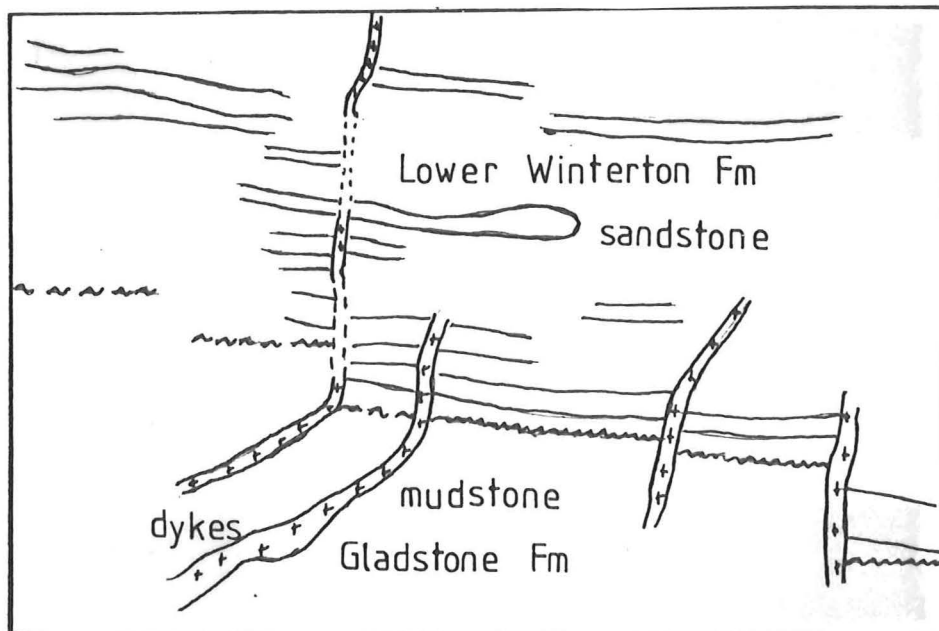
Fig. 2.9

Lower Winterton Fm sandstone overlying Gladstone Fm mudstone. Note that the contact is offset by faults which subsequently have been intruded by dykes.

SKETCH OF FIG. 2.9

Fig. 2.14

Feldspathic sandstone channels in the Lookout Fm basalts.



## THE UPPER WINTERTON FM (New Name)

### 1. Name and Description

The name Upper Winterton Formation is proposed for a sequence of mildly to poorly indurated, sparsely fossiliferous, steeply to mildly tilted, marine, interbedded sandstones, siltstones, mudstones, and conglomerate. The unit is a restricted redefinition of Challis's (1966) Winterton Fm.

The sandstones are occasionally carbonaceous, moderate to well sorted, moderately to poorly cemented, fine to very fine grained, feldspathic, lithic, arenites. Sandstone beds are massive, parallel and cross laminated, and rippled; compound sandstone/conglomerate beds are graded, frequency graded, and bedded. Flame structures, load clasts, sole marks, convolute laminae, and current lineations are also common. Conglomerates are massive and bedded, clast or matrix supported, generally have sandy matrix, and contain clasts from boulder to granule size. Mudstones may be structureless or have interlamination of silt.

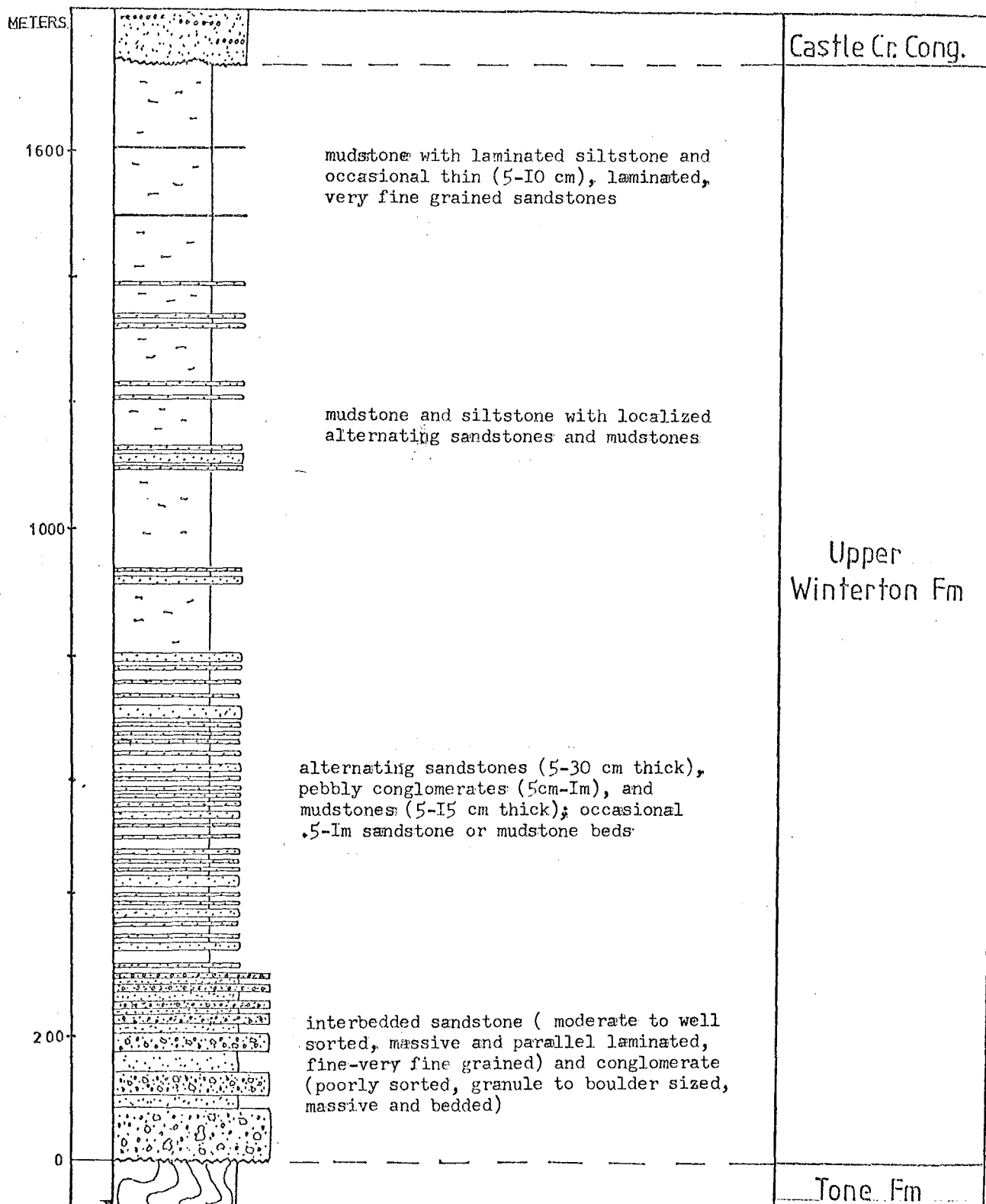
Generally, the formation is a fining upwards sequence. Sandstone beds are generally thin (10-40 cm thick) but may be up to 5 m thick near the base. Conglomerates are abundant only in the basal facies and may be in beds over 30 m thick. Thick (5 m<sup>+</sup>) mudstones dominate the top of the formation.

Structurally, the formation is steeply to mildly tilted and locally riddled with dykes and small faults.

### 2. Type Area

The Upper Winterton Fm is thick and well preserved in

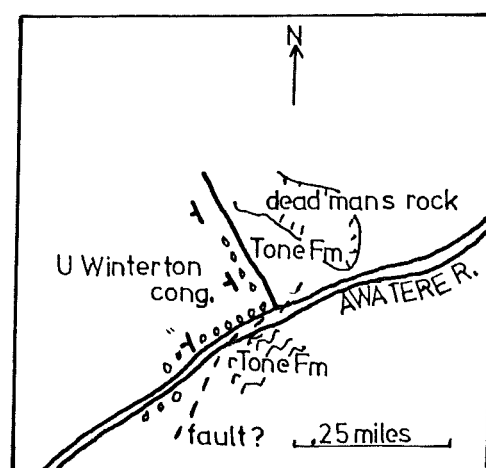
Fig 2.10



the area between the Upper George River and Mt. Lookout. However, the exposure is too obscured for a single type section, so a Type area is proposed instead. The reference section (fig 2.10) shows 250-300 m of conglomerate and sandstone at the base, which is overlain by 1100 m of alternating sandstones and mudstones in various proportions; the sequence is capped by 150-200 m of dominantly mudstone. In this area the base of the Upper Winterton rests discordantly on the Tone Fm and the top is overlain unconformably by the Castle Creek Conglomerate.

### 3. Relationship to Other Units

The Upper Winterton unconformably overlies the Tone Fm along most of the George River. Exposures are particularly good at S41/779, 344, S41/767, 354, S41/775, 350, S41/795, 350, where gently dipping, moderately indurated sandstones, pebbly-sandy conglomerates, and cobble-pebble conglomerates overlie deformed, well indurated, flysch-like rocks of the Tone Fm. In the uppermost Winterton River (S42/843, 387), the basal Upper Winterton conglomerates unconformably and discordantly overlie the Gladstone Fm. Around Mt. Winterton, the Upper Winterton overlies the Lower Winterton unconformably but without angular discordance. In the Awatere River near Dead Man's Rock (S35/856, 484) the Upper Winterton Fm - Tone Fm contact is both faulted and depositional. As fig 2.11



shows, some 500 m of conglomerate appears to depositionally overlie the Tone Fm on the north side of the River; the actual contact is obscured but runs parallel to the strike of the Upper Winterton Fm. On the south bank, however, Tone-like rocks crop out directly across the river from the Upper Winterton conglomerates, suggesting that the two are separated by a fault which lies in the riverbed.

The Upper Winterton Fm is overlain unconformably by the Castle Creek Conglomerate and the Lookout Fm.

#### 4. Distribution and Thickness

The Upper Winterton Fm is the thickest and best preserved unit above the Tone Fm. The formation is thick (1600 m<sup>+</sup>) in the Upper George River and lower Awatere River (Dead Man's Rock) areas, where the basal conglomerate infills a deep channel (see Chapter 3). However, the Upper Winterton Fm thins rapidly to the NW and is absent in Castle Creek; the formation is also missing to the SE at the Bowling Green outlier (S42/826,361).

#### 5. Age

Wellman (in Challis 1966) reports the fossils Aucellina euglypha, Inoceramus aff urius, and Inoceramus ipuanus in rocks mapped as Upper Winterton Fm, indicating a Motuan age.

#### 6. Interpretation

The Upper Winterton is a fining upward, flysch-like sequence similar to the Gladstone and Lower Winterton Fms. The Upper Winterton is also a small basin fill but was deposited during more stable conditions than the preceding two cycles.



## THE CASTLE CREEK CONGLOMERATE (New Name)

### 1. Name and Description

The name Castle Creek Conglomerate (named from Castle Creek) is proposed for a thin sequence of mildly lithified, unfossiliferous, tilted, white to grey coloured, sandstone and pebbly conglomerate.

The sandstones are moderately well to well sorted, very fine grained, carbonate concretionary, mildly cemented, feldspathic, lithic arenites. The beds look massive but in stream section they are faintly parallel laminated. The formation is not resistant and so exposure is limited; the distinctive well rounded and polished pebbles which occur in float may be the only clue to the presence of the unit. The pebbly conglomerates occur as thin lenticular beds within the sandstone and are supported by a sandy matrix.

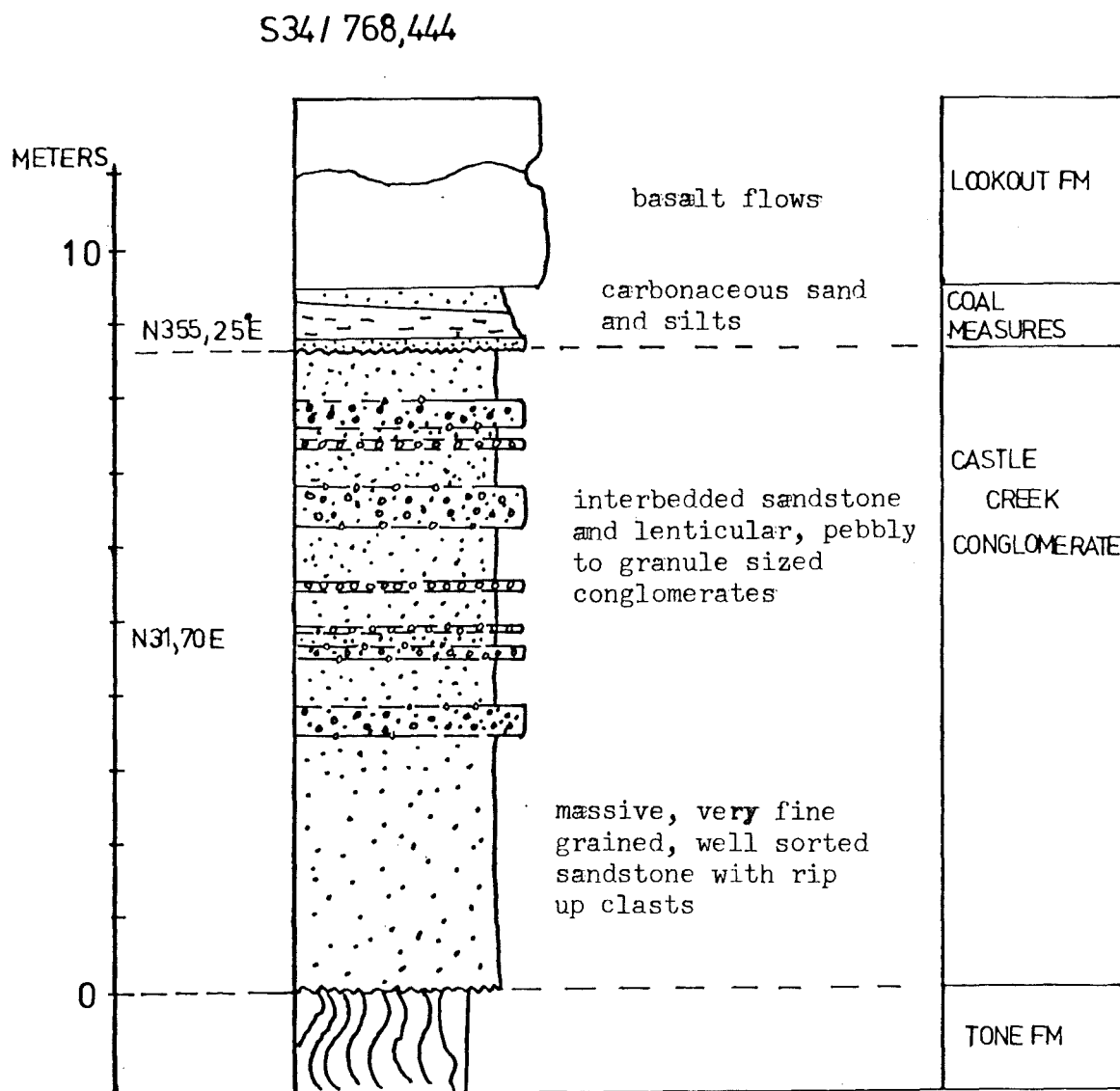
### 2. Type Section

The type section was measured in a gully near Castle Creek (S34/768,444) and is shown in fig 2.12. Although the type area is thinner than the exposures in Middelhurst stream, the unit remains fairly uniform. The pebbly conglomerate beds always appear near the top of the section but the lower sandstones commonly have floating rounded pebbles or mud rip up clasts.

### 3. Relationship to Other Units

The Castle Creek Conglomerate unconformably overlies the Tone Fm at Castle Creek and east of Middelhurst station at S34/777,420. In Middelhurst Creek, the Castle Creek

Fig 2.12



Conglomerate unconformably but concordantly overlies the Upper Winterton Fm. The Castle Creek Conglomerate is always overlain by the Lookout Fm; in Castle Creek and Middelhurst Creek the contact is an angular unconformity; below Mt. Lookout and in the south branch of Old Middelhurst Stream the contact is erosional without being obviously discordant.

#### 4. Distribution and Thickness

The Castle Creek Conglomerate varies from about 10 m in Castle Creek to 50 m below Mt. Lookout. Along Middelhurst Creek, the Castle Creek Conglomerate is eroded away in several places and the Lookout Fm rests directly upon the Upper Winterton Fm. These localities lie on the upthrown side of minor faults, suggesting that the faults were active after Castle Creek Conglomerate deposition but before the Lookout Fm. The Castle Creek Conglomerate is missing from the area just below the head of Old Middelhurst Stream (south branch) to the Awatere River-Winterton River confluence and appears to have been eroded away.

#### 5. Age

Lensen (1962) mapped the Castle Creek Conglomerate as Ngaterian, but does not cite any fossil evidence. Challis (1966) considered the Castle Creek Conglomerate to be part of her Winterton Fm of Motuan age. Aucellina euglypha is present just below the Castle Creek Conglomerate in Middelhurst Creek (S41/f555) and fossils in the overlying Lookout Fm are Ngaterian; so the Castle Creek Conglomerate is no older than Motuan and no younger than Ngaterian.

## 6. Interpretation

The Castle Creek Conglomerate resembles some of the basal sandy conglomerates of the Upper Winterton Fm (exposed at S41/779,344) and is likewise interpreted to be the basal facies of a once more extensive marine, flysch-like unit which was subsequently almost entirely eroded away. Thus the Castle Creek Conglomerate is regarded as the basal portion of another fining upwards cycle similar to the Upper Winterton, Lower Winterton, and Gladstone Fm.

### THE LOOKOUT FM (Challis, 1966)

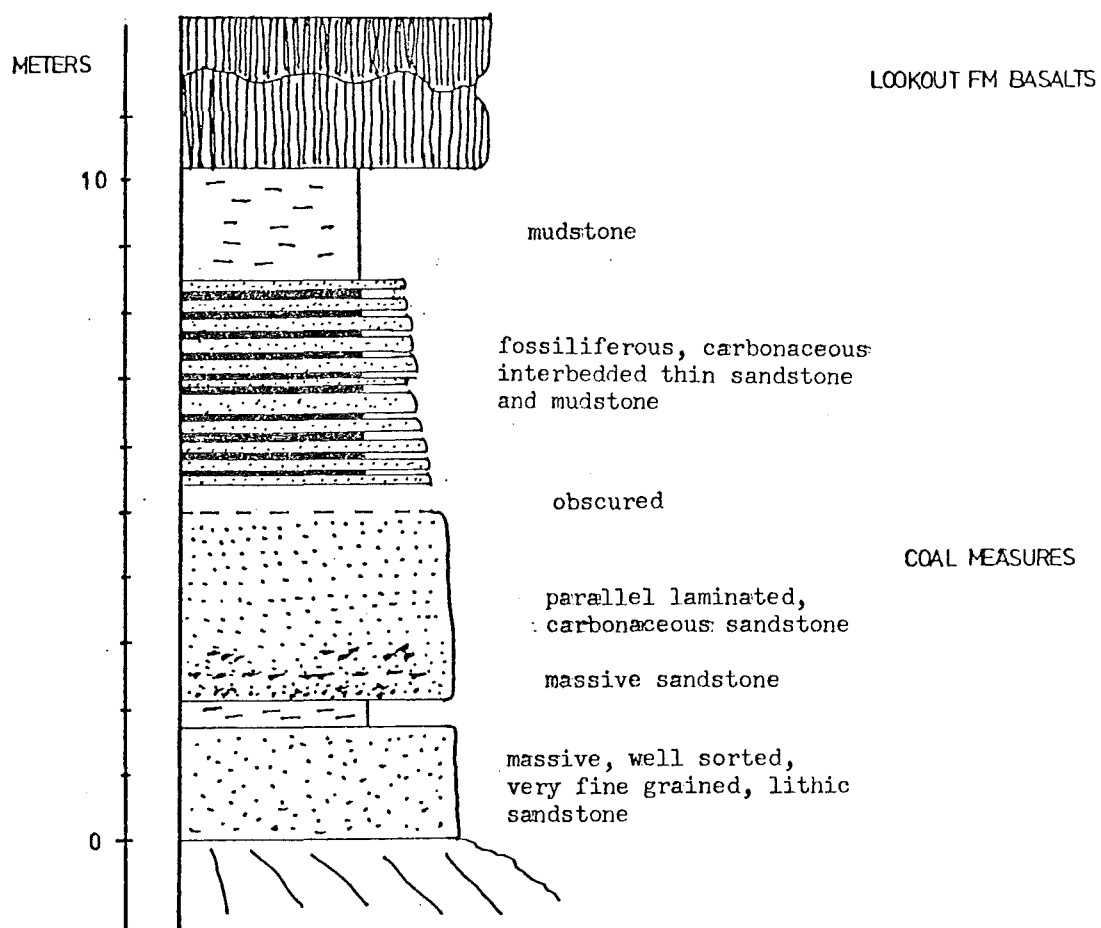
#### 1. Name and Description

The Lookout Fm (named for Mt. Lookout) is defined by Challis (1966) as 1000 m<sup>+</sup> of basalt flows, interbedded tuffs, agglomerates, and limestone pods. Two modifications are proposed: 1) that the coal measures be reassigned to the Lookout Fm and 2) that a new informal unit, the Bowling Green Conglomerate, be added to the Lookout Fm.

As seen in fig 2.12, the coal measures are conformably overlain by Lookout Fm basalt flows, but discordantly overlie the Castle Creek Conglomerate. Therefore the coal measures should belong to the Lookout Fm. This same relationship is preserved in Middelhurst Creek (at S41/779,390), where carbonaceous, parallel laminated silt and sand unconformably overlie the Castle Creek Conglomerate. The coal measures have occasional Inoceramus fragments and a horizon of Inoceramus fragments just below the first lava flow at S41/779,390. The best exposure lies at S35/835,463 and is

Fig 2-13

S35/835,463



shown in fig 2.13. The coal measures are interpreted as marginal marine.

The Bowling Green Conglomerate is a newly discovered outlier of massive, poorly sorted, boulder to granule sized, rounded to angular clasts, clast and matrix supported conglomerate with a poorly sorted, coarse sand to silt matrix. The conglomerate is principally composed of detritus similar to the Lookout basalts and the unit is cut by the Tapuaenuku Dyke Swarm; thus, the Bowling Green Conglomerate is thought to be contemporaneous with the Lookout Fm. The conglomerate rests unconformably on the Tone Fm at S42/826,361 and is bounded on the NW side by a fault, which was subsequently intruded by a dyke.

The bulk of the Lookout Fm is composed of interbedded basalt flows which are subareal through most of the formation but become marine pillow lavas near the top. Near the base, sandstone lenses are commonly interbedded with the lavas (fig 2.14). These sandstones are massive, well sorted, very fine grained, feldspathic, lithic arenites with a clay matrix. The flows are full of local unconformities (fig 2.14) which suggests intermittent eruptions.

The morphology of the basalts is a pancake arrangement of discontinuous, pinching and swelling lava flows. Flows commonly have both their bases and tops altered, giving the appearance that there are voluminous tuffs between them, when in fact the interbedded tuffs are thin. The common alteration pattern is illustrated in fig 2.15. The interbedded tuffs and basal breccias of the flows are quite porous, for springs commonly occur in them; these permeable zones have enabled percolating waters to chemically weather the upper and lower portions of each flow. In the lower part of the formation,

flows stack up on each other as in figure 2.15 for hundreds of meters; this can be clearly seen at Castle Creek. In the upper part of the Lookout Fm, interbedded tuffs become thicker than the flows, as in fig 2.16. Challis (1966) reported limestone pods in the pillow lavas and I. Speden (pers.comm.) discovered similar limestones in the Lookout Fm in Limestone Creek. The exposure of the pillow lavas was poor and so I was unable to relocate Challis's limestone locality.

The Lookout Fm basalts were described geochemically by Nicol (1977) as an ankaramite-Trachybasalt-transitional trachybasalt-trachyandesite series. In the field the basalts could be distinguished according to the phenocryst size. Three general types of coarsely porphyritic lavas were identified: 1) augite dominated megaphenocrysts with varying proportions of subordinate olivine and opaques, 2) augite, olivine, and plagioclase phenocrysts in varying proportions, and 3) plagioclase dominated phenocrysts with subordinate augite and olivine. Challis (1966) describes trachytes as well, but I was unable to relocate the exposure. The pillow lavas were distinct from the sub<sup>e</sup>ar<sup>l</sup> flows in being micro-porphyritic usually with black clinopyroxene, weathered olivine, and faint plagioclase microphenocrysts. Challis (1966) concluded that the pillow lavas were not spilitic, but the extinction angles off plagioclase albite twins ( $10^{\circ}$ - $15^{\circ}$ ) looked to me to be significantly lower than the plagioclase phenocrysts or microphenocrysts in the subar<sup>l</sup> basalts ( $30$ - $35^{\circ}$ ).

Although Nicol (1977) determined three geochemical cycles in the Lookout lavas, the field characteristics which stand

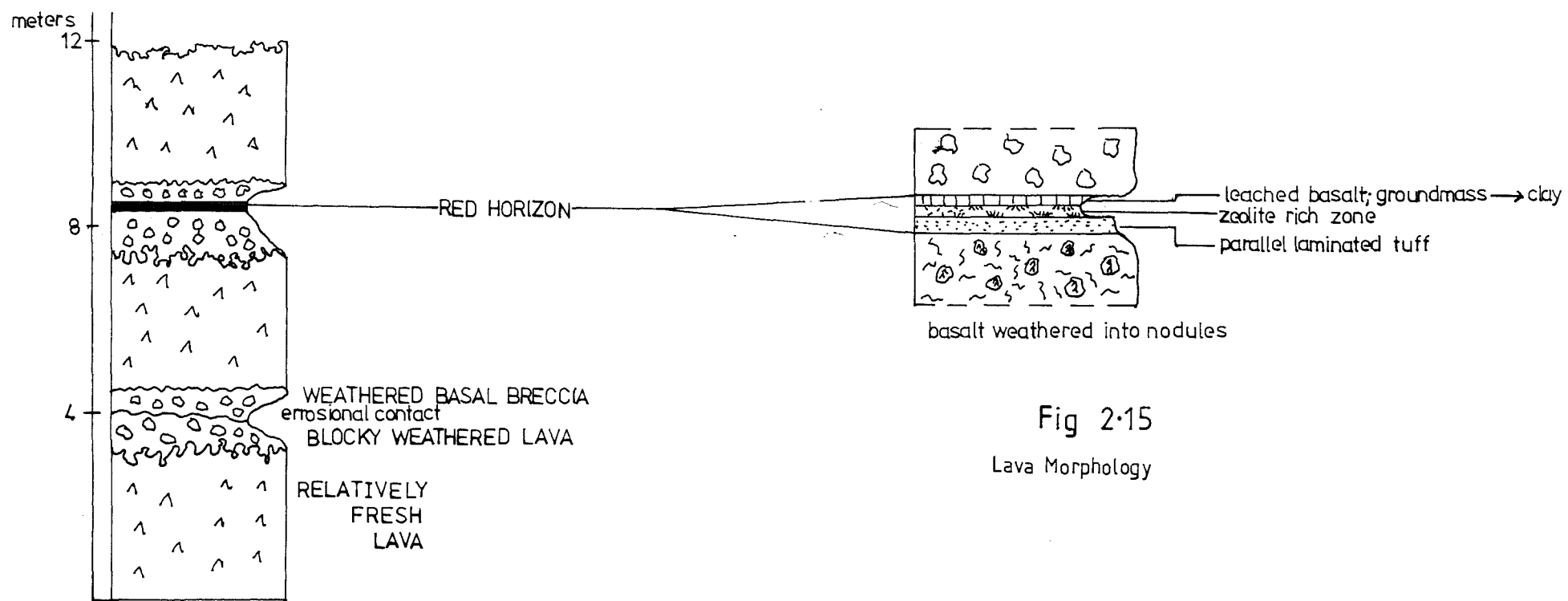
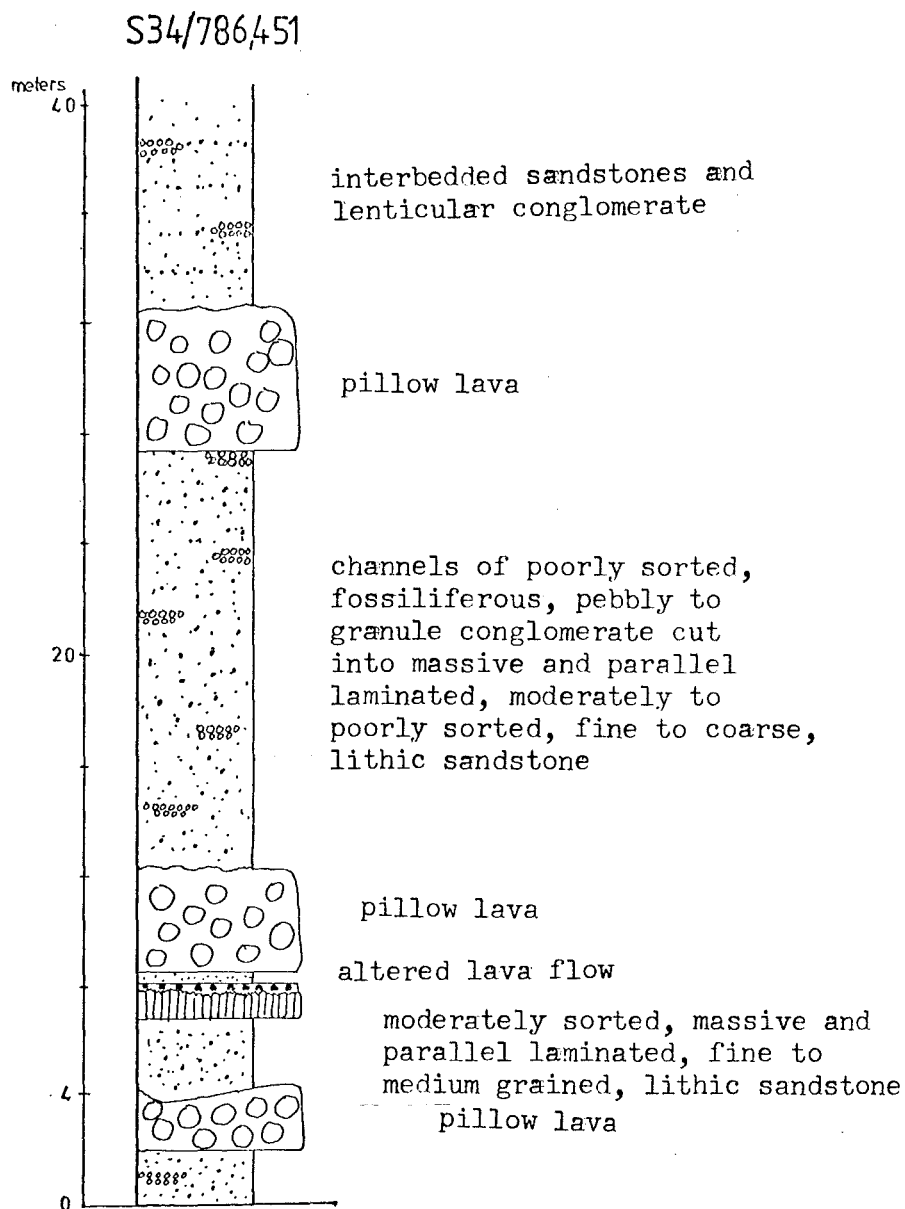


Fig 2.15  
Lava Morphology



Fig 2.16



out the most is alteration. In the lower lava flows in Middelhurst Creek, the alteration veins and vugs are dominated by quartz, carbonate, chlorite, and zeolites (analcime), but in the upper flows along Mt. Upcot ridge the alteration products were fibrous natrolite and thomptsonite with zoned interiors of carbonate (fig 2.17). The lower flows are blocky and weathered red while the upper flows have a smooth surface and a brown color. Alteration appears most intense along Mt. Upcot ridge, where the rock is perforated with micro and macro vesicles. Much more work on the alteration of the Lookout Fm is needed, but it is likely that the formation has secondary alteration zones as well as primary geochemical zones.

Structurally, the Lookout Fm is grossly an inclined sheet which steeply and mildly dips to the NW. The unit becomes progressively more faulted toward the Awatere fault; although there is some local folding, the structure is dominantly tilted fault blocks.

## 2. Type Section

Challis's (1966) type section locality was obscured by scrub and float. The intensity of faulting prevents the exposure of a complete stratigraphic section so it is difficult to propose a useful type area.

## 3. Relationship to Other Units

The Lookout Fm overlies the Castle Creek Conglomerate and/or Upper Winterton Fm unconformably at Castle Creek, Middelhurst Creek (fig 2.18), Old Middelhurst Stream, and the Awatere River. The formation is faulted against

"Greywacke A" (Challis 1966) in the region close to the Awatere fault and against late Cretaceous, early Tertiary sediments in Lee Brook. At the Bowling Green outlier, the Lookout Fm unconformably overlies the Tone Fm.

#### 4. Distribution and Thickness

Since there is no preserved section from base to top and since no internal marker horizons have been mapped, it is very difficult to determine true thickness and thickness variations. Previous workers (Challis 1966, Nicol 1977) considered the Lookout Fm to be part of an extensive sheet of lava flow at least 1000 m thick. The thickest single unfaulted exposure appears on the north side of the Awatere River opposite the mouth of Old Middelhurst Stream and it approaches 600 m thick, so the estimate of 1000 m appears reasonable.

#### 5. Age

Dating of Lookout Fm lavas by P.J. Oliver (in Reay, 1980) suggests the formation is 99.7-97.1 m.yr. old. Wellman's (in Challis 1966) identification of Inoceramus tawhanus in the upper marine tuffs suggests a Ngaterian age.

#### 6. Interpretation

The Lookout volcanics are apparently petrogenetically related to the Tapuaenuku Dyke Swarm, the Tapuaenuku Plutonic Complex, the Blue Mountain Igneous Complex, and the Gridiron volcanics (Nicol 1977). Both Nicol (1977) and Challis (1966) interpret the Lookout Fm as the preserved remnant of a once extensive sheet. However, some evidence suggests that the unit is a local accumulation. The inter-

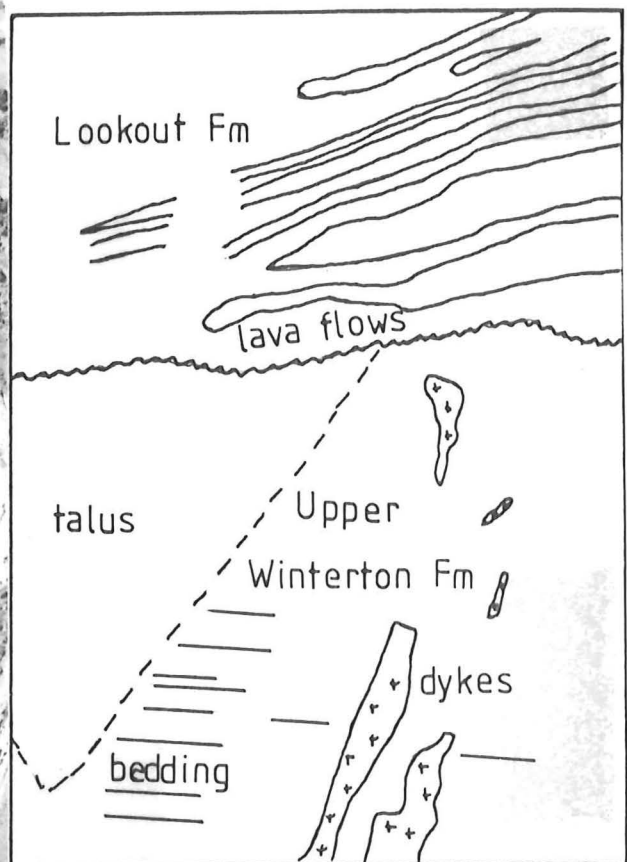
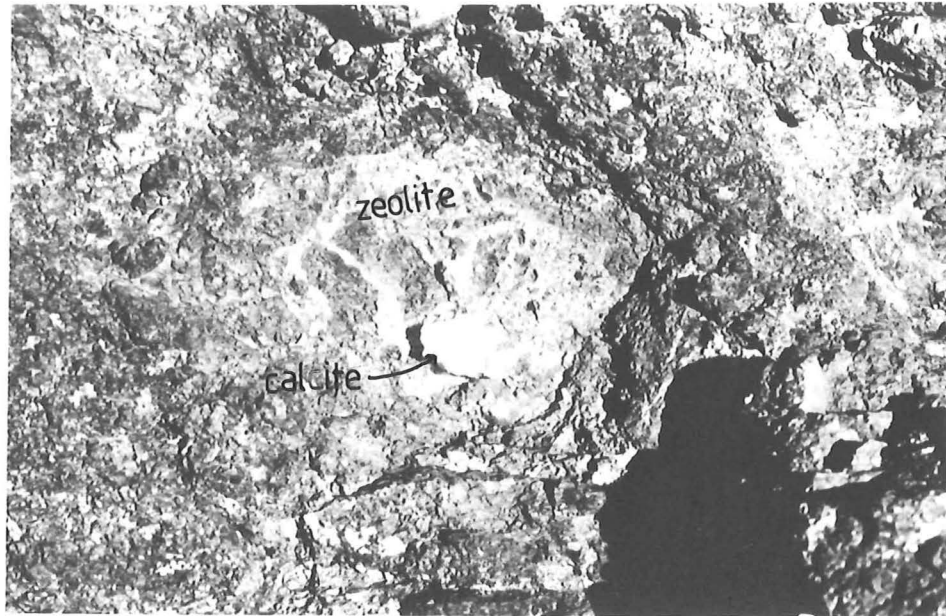
Fig. 2.17

Alteration vein in Lookout Fm basalts  
(Note mineral zoning)

Fig. 2.18

Lookout Fm unconformably overlying the  
Upper Winterton Fm (Castle Creek Conglomerate  
is obscured by volcanic debris)

SKETCH OF FIG. 2.18



bedded feldspathic channel sandstones in the lower part of the formation suggests that drainage flowed into the area, rather than out from it - signifying that the Mt. Lookout area was a depression rather than a high. Although there are local unconformities, the volcanic sequence lacks filled channels or thick debris flows, suggesting that there was never much relief. The overall thinness (2-5m) of the flows and their discontinuous, lenticular shape suggests rather localized eruptions. Extensive flood basalts, such as the Columbia River Basalts, have thick lava flows which correlate over several kilometres. The transition from terrestrial conditions at the base to marine conditions at the top of the formation suggests that eruptions failed to keep pace with subsidence, causing a marine transgression. Thus, an alternative explanation for the Lookout Fm is that it represents a localized subsiding basin where lava flows ponded and accumulated in unusual thicknesses. The thickness of the Lookout Fm (1000m<sup>+</sup>) suggests the subsidence was in part fault controlled; the development of the underlying formations supports this idea.

No central vents or vent was recognized, there was a general lack of pyroclastic material, and the dykes decreased in number upwards through the volcanic pile. Though observable examples of dykes feeding flows were rare, I agree with Challis (1966) and Nicol (1977) that the lava flows were primarily erupted from the Tapuaenuku Dyke Swarm.

#### THE TAPUAENUKU DYKE SWARM (Nicol 1977)

##### 1. Name and Description

Nicol (1977) classified the Tapuaenuku Dyke Swarm as

part of the Tapuaenuku Igneous Complex and defined the dyke swarm as a radial set of dykes around Mt. Tapuaenuku.

In the study area, the dyke lithologies were similar to the Lookout basalts, although some dykes were far richer in plagioclase and amphibole (kaersutite) than any observed lava flow. The dykes were generally .5 to 1.5 meters thick, had straight or sinuous boundaries, generally lacked glassy margins, but were frequently porphyritic in the centre and microporphyritic near the margins. The dykes intruding sediments were heavily altered, especially near the margins, to chlorite and zeolite while carbonate was seen replacing phenocrysts and the groundmass. Some of the dykes intruded along pre existing faults; fig 2.9 shows a series of small faults intruded by dykes. Note also that the dykes suddenly change their orientation when changing from a mudstone to a sandstone dominated host rock. This "kinking" of the dykes between lithologies is common.

### 3. Relationship to Other Units

The dykes intrude all the formations up to and including the Lookout Fm.

### 4. Distribution

The dykes crop out with intensity from the Middle George River, through Mt. Winterton, to the south side of the Awatere River (see Map 2). The dyke swarm becomes particularly dense in the Totara Stream-Gladstone Stream area; unfortunately this is not apparent on Map 2 because the rugged topography made mapping on foot or by <sup>a</sup>erial photos difficult. The dyke swarm gradually changes its orientation from N65°W north of the Winterton River to S85°W around the George River,

an angle of  $30^{\circ}$ . Statistical analysis by Nicol (1977) of the orientations of the dykes suggested that the dykes all came from the same population. However, as mapped, there does appear to be two slightly oblique <sup>ca.</sup>liniments: one trending ENE through Mt. Winterton and another trending NE just south of the upper Winterton River. Such features are hidden by the statistics of Nicol. More detailed mapping and sampling of the dyke swarm is needed.

### 5. Age

Potassium argon dating on one unusual tholeiitic dyke in the George River yielded a  $88.6 \pm 0.7$  m.yr. date while a pegmatite in the Hodder River gave a  $98.9 \pm 0.7$  m.yr date (Nicol 1977). Since the younger date comes from a compositionally unique dyke, the older date appears to be more reliable and agrees with the dates on the Lookout basalts. Much more dating remains to be done.

### 6. Interpretation

The dyke swarm forms the principal eruptive centres for the Lookout basalts as interpreted by Challis (1966) and Nicol (1977). There are at least 300 dykes between the George River and Tame Stream, a distance of 15 km. Given that the average dyke is 1 m thick, this represents a minimum extension of 20m/km or 2%. Nicol (1977) interpreted the dykes as a radial swarm around Tapuaenuku. However the regional orientation of the dykes as shown on Map 3 appears to follow a conjugate set of <sup>ca.</sup>liniments. Much more detailed mapping of the dyke swarm is necessary to test Nicol's hypothesis.



## MATA SERIES

In Lee Brook, McQueen's Culvert, and Scruby Creek there are scattered outcrops of poorly lithified, carbonaceous, well sorted, grey, fine to very fine grained, quartzofeldspathic, glauconitic, lithic sandstones and siltstones. Siltstone beds are usually 5-30 cm thick, but some exceed 1 m. Sandstones vary from 10 cm to 1 m thick and may be parallel and cross laminated, rippled, with occasional (1-3 cm) coarse basal deposits. In Scruby Creek, the silts are micaceous. Similar lithologies crop out near Glen Lee Station and have been dated as Haumurian on microfossils (Challis 1966). The distinct mineral differences between these rocks and the Clarence rocks and the time break between the Mata rocks and Clarence rocks suggests that the Haumurian rocks unconformably overlie the Lookout Fm.

## DANNEVIRKE SERIES

The Amuri Limestone crops out in fault bounded slices along much of the Awatere River from Limestone Creek to Lee Brook. In Lee Brook there is a good exposure of fractured, micritic limestone which has been dated as Mangaotanean (Challis 1966) on foraminifera. No depositional contacts have been discovered.

## STRATIGRAPHIC RELATIONSHIP BETWEEN TORLESSE-LIKE AND OVERLYING ROCKS

### 1. The Contact between the Tone and Younger Units

Lensen (1962) mapped the stratigraphy in a layercake

fashion where his Taitai unit was everywhere overlain by Urutawan rocks, which were in turn overlain everywhere by Motuan rocks. Challis (1966) has a similar interpretation in the George and Winterton Rivers, but does have the Winterton Fm directly overlying Torlesse-like rocks in Middelhurst Creek and Castle Creek. This thesis has five separate unconformities which separate the Torlesse-like Tone Fm from overlying units. The oldest unconformity is at least Motuan and possibly Urutawan, while the youngest is Ngaterian; thus the unconformities span a duration of time roughly equivalent to the Oligocene.

It may be that the unconformity separating the Tone from overlying rocks is a single surface upon which progressively younger units have lapped on. Seismic data from present continental margins shows that marine "onlap" units occur during periods of shelf or platform erosion (Vail et al 1977, Brown and Fisher, 1978). Thus, rather than an inactive erosion surface becoming progressively buried by younger and younger strata, ongoing erosion makes the age of the unconformity surface progressively younger. Therefore, even if the Mt. Lookout Stratigraphy represents progressive burial of submarine relief, it is very unlikely that any of the erosion surfaces separating the Tone Fm from overlying units are the same age.

The youngest Clarence units (The Lookout Fm and the Castle Creek Conglomerate) are separated from the Tone Fm by the longest hiatus and consequently these units differ from the Tone Fm in induration and structure. As the Clarence formations become older, the hiatus separating them from the Tone Fm becomes smaller and the distinction between Torlesse-like and post Torlesse rocks becomes rather subtle.

This suggests that rather than a sharp break between Torlesse and Post Torlesse rocks represented by a single regional unconformity that the Tectonic significance of the unconformity is growing over time and that the change from Torlesse to Post Torlesse conditions is evolutionary.

#### NOMENCLATURE FOR DISCUSSION

To aid the discussion in the following chapters, various terms are here introduced. For the sake of description, the Tone, Totara, Gladstone, Lower Winterton, Upper Winterton formations, and Castle Creek Conglomerate will be collectively referred to as the "Middelhurst succession". The "upper Middelhurst succession" refers to the Lower Winterton Fm, Upper Winterton Fm, and Castle Creek Conglomerate; the "lower Middelhurst succession" refers to the Tone, Totara, and Gladstone Formations. The reader is reminded that these terms have no formal standing.

## CHAPTER 3: SEDIMENTARY FACIES

### INTRODUCTION

The purpose of this chapter is to describe, and interpret the depositional facies of the sedimentary formations and to examine the differences in environment between the basement (Tone Fm) and overlying units.

The sedimentary facies and succession of the Castle Creek Conglomerate, Upper Winterton Fm, Lower Winterton Fm, and Gladstone Fm all appear roughly similar. The Upper Winterton Fm is the best exposed and preserved unit and so is examined in the most detail. The Totara Fm is not treated in detail here because it is intensely deformed and the succession of facies is difficult to obtain. The Tone Fm is relatively uniform and is discussed separately.

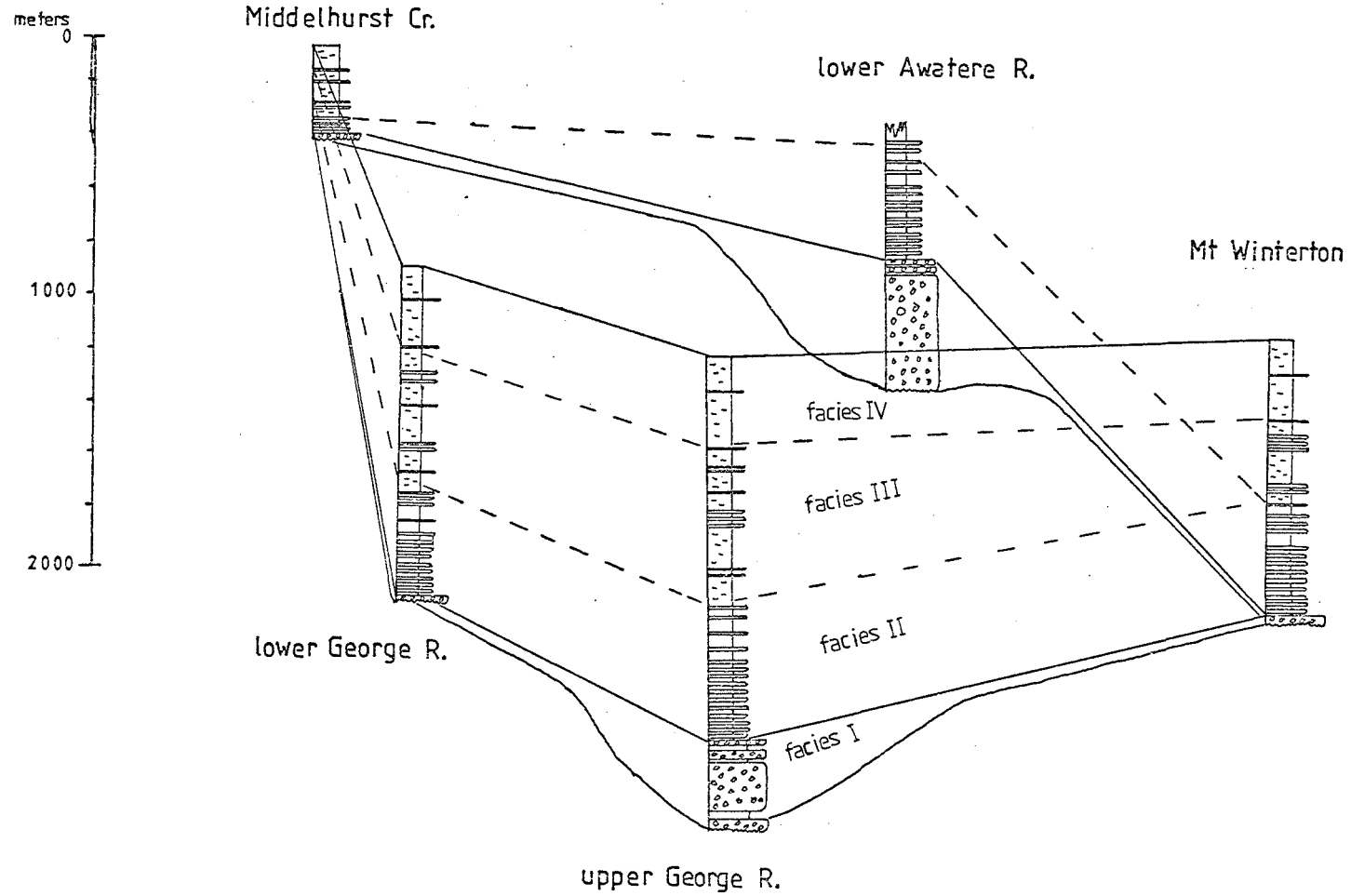
### THE UPPER WINTERTON FM.

The Upper Winterton Fm has been subdivided into four facies illustrated in fig 3.1. The overall trend is a fining upwards sequence and individual facies retain their stratigraphic superposition throughout the outlier. The contact between each facies is gradational and the four facies together are interpreted collectively as a single depositional cycle.

#### 1. Facies I.

Facies I is a conglomerate dominated sequence with interbedded sandstones but no mudstones. The lensoidal geometry of this facies suggests a channel fill (fig 3.1). Thick channel

Fig 3-1 diagrammatic sketch of Upper Winterton facies



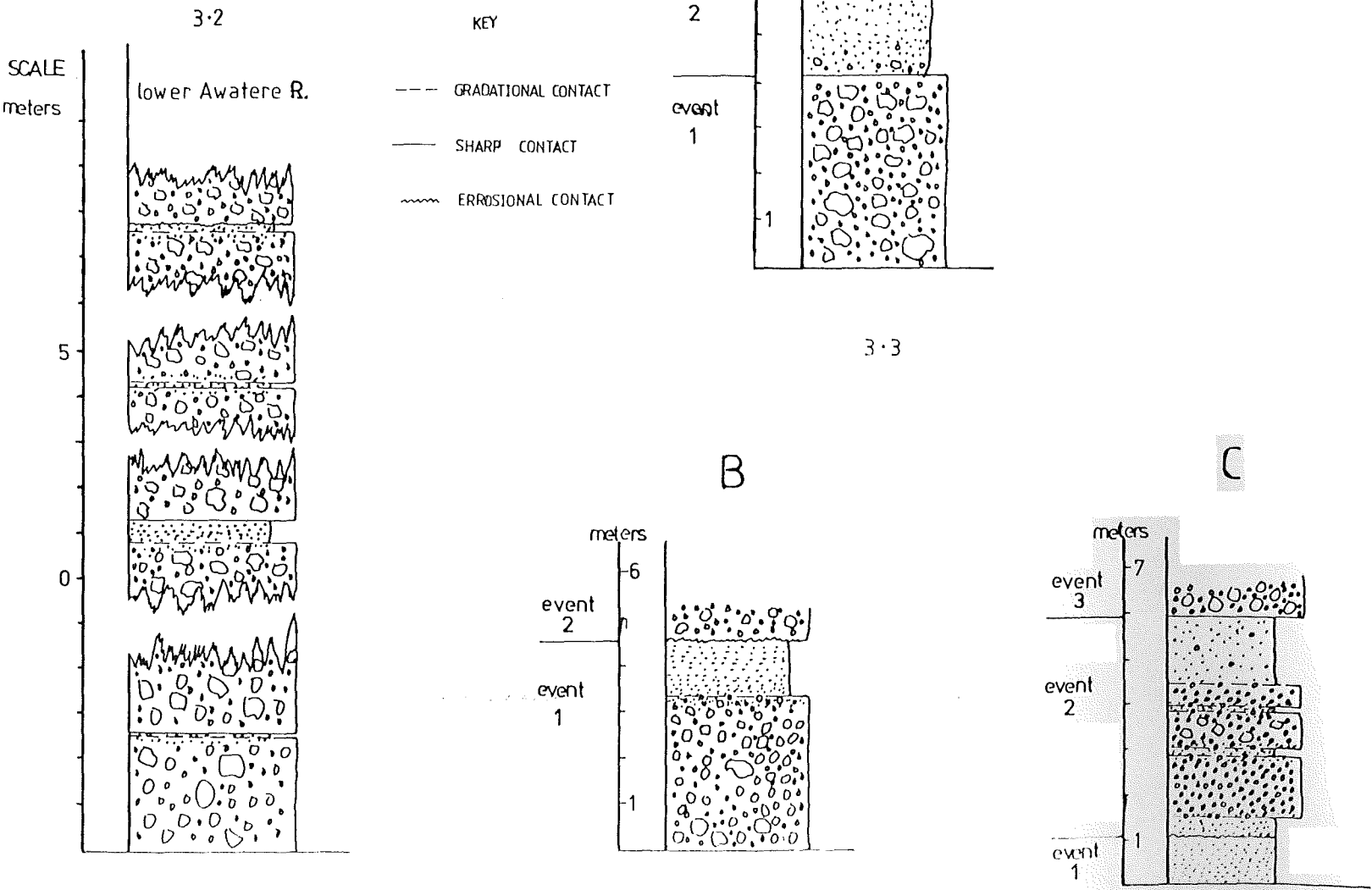
fill sections crop out in the upper George R. (500m thick) and the lower Awatere R. (near Dead-Mans Rock) (800m thick). Paleocurrent directions for both areas trend N-NE, suggesting that the lower Awatere section is depositionally down dip from the upper George R. section.

The lower Awatere section contains thick ( $100\text{m}^+$ ) beds of conglomerate which decrease in thickness up section; sandstones are a subordinate lithology but increase in percentage and bed thickness up section. The conglomerate fabric is mostly structureless but occasionally clasts are aligned parallel to bedding. The conglomerate framework is dominantly clast supported with very thin (centimeters thick), matrix supported zones adjacent to sandstone beds. Framework clasts comprise cobbles, pebbles, and occasional boulders; at the top of the section boulders are absent and pebbles predominate. The matrix consists of poorly sorted, granule to silt sized, material; the dominant size being very fine or fine grained sand. In contrast, the interbedded sandstones were commonly parallel laminated, moderately well to well sorted, fine to very fine grained, arenites with scattered lenses of poorly sorted, coarse to very fine grained, sand. Figure 3.2 is a composite section, taken from various parts of the lower Awatere channel fill; the figure shows that sandstones generally have gradational basal contacts with conglomerate and erosional upper contacts. This suggests that the sandstones represent either a period of lower current competence (in-between conglomerate depositional events) or a decrease in the supply of conglomerate.

The upper George R. channel fill is significantly thinner and sandier than the lower Awatere channel fill. The thickest conglomerate bed (10m) occurs at the base of the section and

FIG: 3.2+3.3

SANDSTONES IN FACIES I



the beds thereafter are between 1 and 6 meters thick; at the top of the section, conglomerate beds are less than 1m thick. The sandstones also have their thickest beds (3-4m) towards the base and thin beds (<1m) at the top. However, the percent sand increases up section while the percent conglomerate decreases. Internally the conglomerates are massive and dominantly clast supported; occasionally there were thin matrix supported regions adjacent to sandstone beds. Framework clasts are mostly cobbles and pebbles with some small boulders near the base. The matrix consists of poorly sorted, granule to very fine grained sand. In contrast, the interbedded sandstones are moderately to well sorted, fine to very fine grained, arenites with occasional "floating" pebbles, pebble laminae, or pebble-granule lenses and laminae of wood fragments. (Individual wood fragments range up to 20 cm long and give good paleocurrent lineations).

The relationships between sandstones and conglomerates are summarized in figure 3.3. In 3.3a, the sandstone has a sharp contact with both the underlying and overlying conglomerate, suggesting that a period of erosion or hiatus separates each unit. Thus, the sandstone is a separate depositional event which may represent background sedimentation between episodes of coarser deposition. In figure 3.3b, the sandstone has a transitional basal contact with the underlying conglomerate and therefore is part of the conglomerate bed. The sandstone may represent a waning current at the end of a depositional episode or a sudden drop in coarse sediment supply. The presence of floating pebbles and cobbles in the 3.3b sandstone suggests the current had the capacity to transport coarse sized material but that little coarse material was available. In



figure 3.3c the bedding contacts between interlayered sandstones and conglomerates (in "event 2") are all gradational; this makes both lithologies part of the same bed. These multiple beds occur only in the upper part of the section and represent either a current or flow with pulsating energy or an irregular supply of coarse material.

Facies I also appears as a thin blanket over a wide area. Figure 3.4 shows that these thin deposits show great variation just in the lower George River area. The overall dominance of sand and pebbles suggests that these deposits correlate with the top of the channel fills. Thus, after the channels had apparently filled, a thin sheet of conglomerate spread out over the topography (fig 3.1).

Interpretations of the depositional agent must account for: 1) the lack of mudstone, 2) the thickness ( $16\text{m}^+$ ) of individual beds, 3) the poorly sorted conglomerates vs. the well sorted interbedded sandstones, and 4) the gradational relationship between sandstone and conglomerate. The two most likely depositional mechanisms are traction currents or mass flows. The conglomerates have internal features which suggest mass flow (poor sorting, chaotic fabric, very thick beds, clast and matrix supported), while the interbedded sandstones have features suggesting traction currents (good sorting, and parallel laminations). If this were so, one would not expect to find gradational contacts between sandstones and conglomerates because traction currents might scour the underlying conglomerate before depositing the overlying sandstone. The interbedded sandstones also show remarkably consistent parallel lamination (up to 3m thick) in a single bed without any rippling or cross lamination; this uniform consistency of flow regime is unusual for a traction

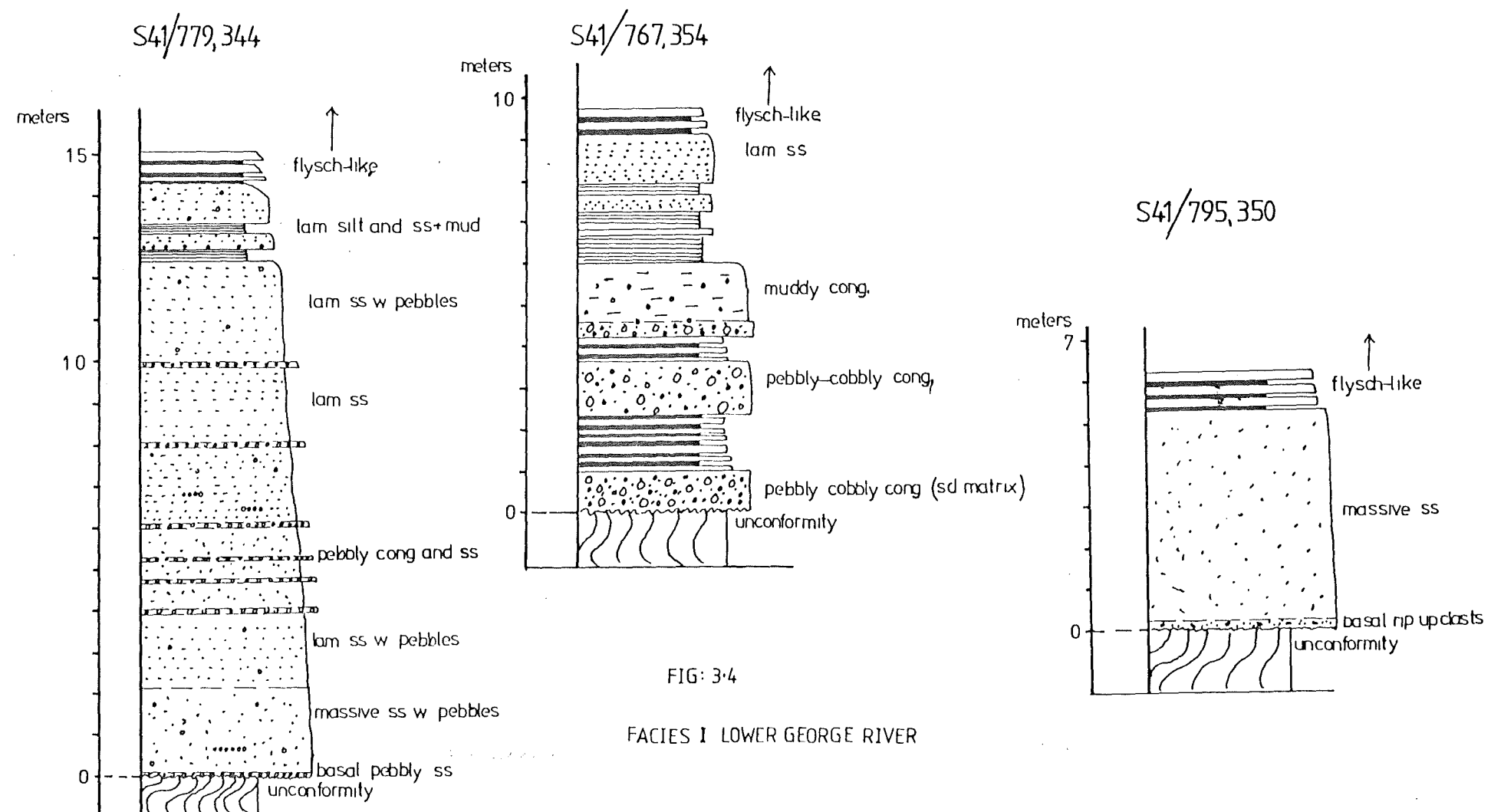


FIG: 3.4  
FACIES I LOWER GEORGE RIVER

current, which commonly waxes and wanes. Other well sorted, parallel laminated sandstones have been interpreted as mass flow deposits (Link and Nilsen 1980, Lewis et al 1980, Lewis 1976) and so a mass flow interpretation is reasonable for both the sandstones and conglomerates. The good sorting of the sandstones may be due to an abundant source of fine to very fine sand up dip. The absence of mudstone and shale suggests either that the channel was filled very rapidly or that erosion preceding each depositional event removed all the mudstone.

Since there is a variety of lithologies in a single bed, the type of mass flow must have changed during a single depositional event. The erosional base preceding deposition is probably due to some sort of base surge; the clast supported conglomerate appears to be one type of flow, the matrix supported conglomerate another kind of flow, and the overlying sandstone a third type of flow. The beds lack bouma-like sequences and therefore are probably not turbidites, rather the process is more likely to be in the debris flow end of the mass flow spectrum (Lowe 1980).

## 2. Facies II.

The thickness of facies II varies directly with the thickness of the Upper Winterton Fm as a whole (fig 3.1). The facies consists of interbedded sandstones, siltstones, mudstones, and occasional conglomerate but is characterized by the overall dominance of sandstone. The beds are much thinner than facies I and range from 5 cm to 1 m thick. For descriptive purposes, the facies is divided into lower and upper sections.

### a) Lower Section

The lower part of facies II consists of alternating thin bedded sandstones and mudstones with thick bedded sandstones and conglomerates (fig 3.5). The lower section is richer in sandstone and conglomerate and has larger maximum bed thicknesses than the upper section.

The thick beds ( $.5\text{m}^+$ ) are lenticular bodies which occur at scattered intervals in the section; the beds consist of sandstone and conglomerate in varying proportions. Texturally, the conglomerate framework contains poorly sorted, granule to cobble sized clasts, but pebbles are dominant. The matrix comprizes poorly sorted, coarse to very fine grained sand. Texturally, the sandstones were moderately to well sorted, fine to very fine grained, sandstones with occasional "floating" pebble, granule, or coarse sand grains.

Figure 3.6 illustrates some common, thick, multiple sandstone-conglomerate beds. 3.6a is a very common bed type, characterized by massive thin bedded (horizontally or inclined) conglomerates, topped by laminated sandstones. In figures 3.7 and 3.8, note the increase in percent sand near the top of the bedded conglomerates and the rapid transition between the conglomerate and sandstone. Compound beds of alternating sandstone and conglomerate layers also occur (fig 3.6b) as in facies I. Rip up clast conglomerates also occur (fig 3.9); these beds consist entirely of localized mud and sand clasts and lack the rounded, well indurated clasts usually found in the conglomerates. Note in fig 3.9 how the conglomerate is bedded and frequency graded.

Like the facies I rocks, these thick multiple beds have characteristics of both mass flow deposits (coarse, poorly sorted, thick, structureless beds) and traction deposits

Figure 3.5

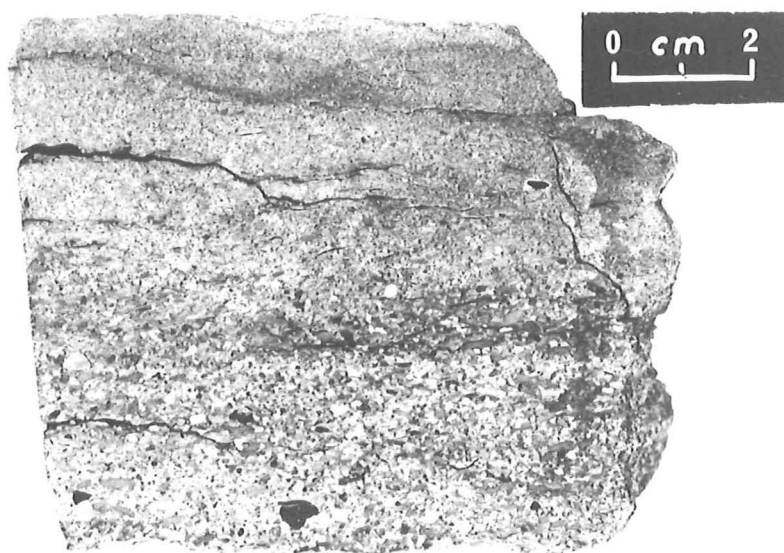
Facies II, Mt. Winterton

Figure 3.7

Cross bedded conglomerate in facies II; note the alternating sand poor and sand rich conglomerate beds; also note the rapid but transitional contact between conglomerate and sandstone.

Figure 3.8

massive and laminated granule-pebbly conglomerate fading into parallel laminated sandstone.



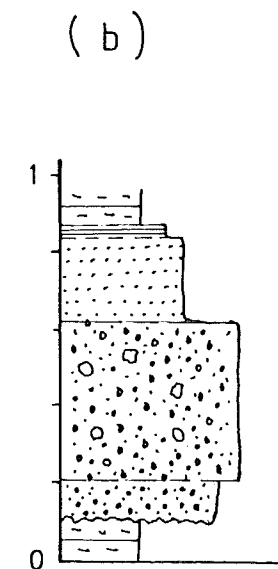
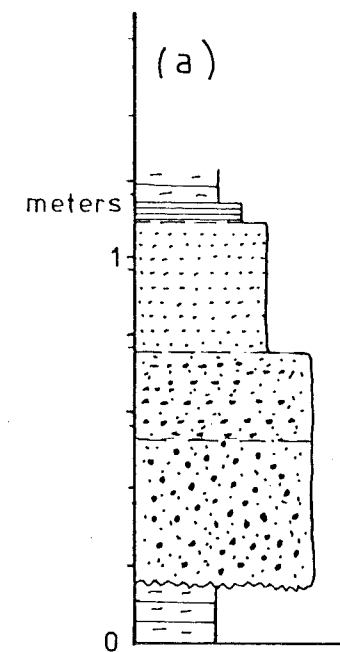
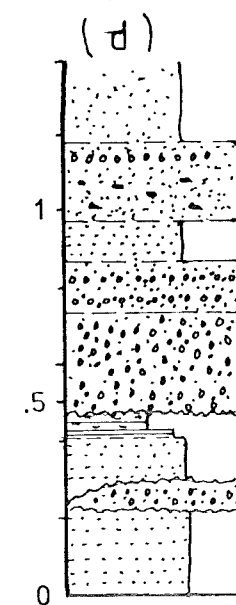
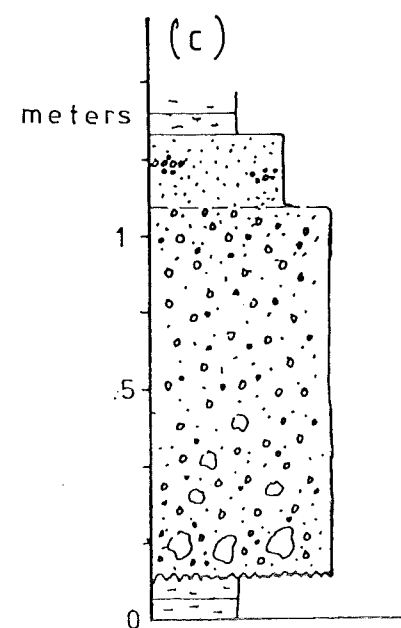
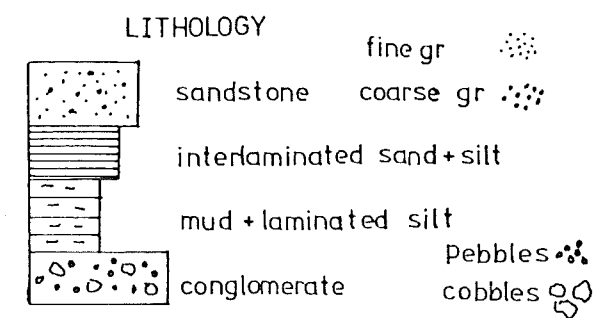


FIG 3.6  
FACIES II SANDSTONES  
and CONGLOMERATE



SEDIMENTARY STRUCTURES

- laminated (parallel)
- massive

BED CONTACTS

- sharp
- transitional
- erosional

Figure 3.9

Rip up clast conglomerate, note the frequency grading.

Figure 3.10

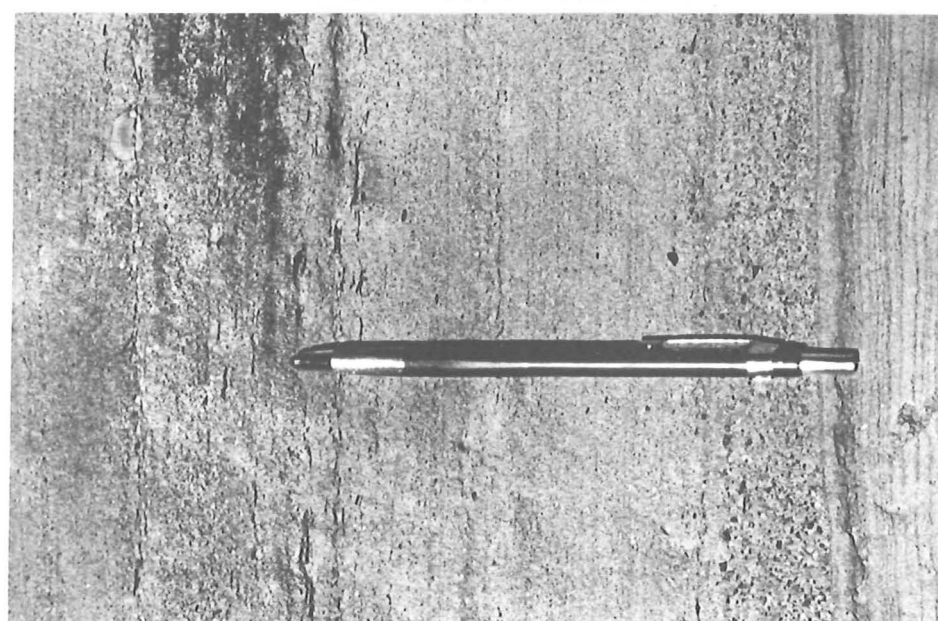
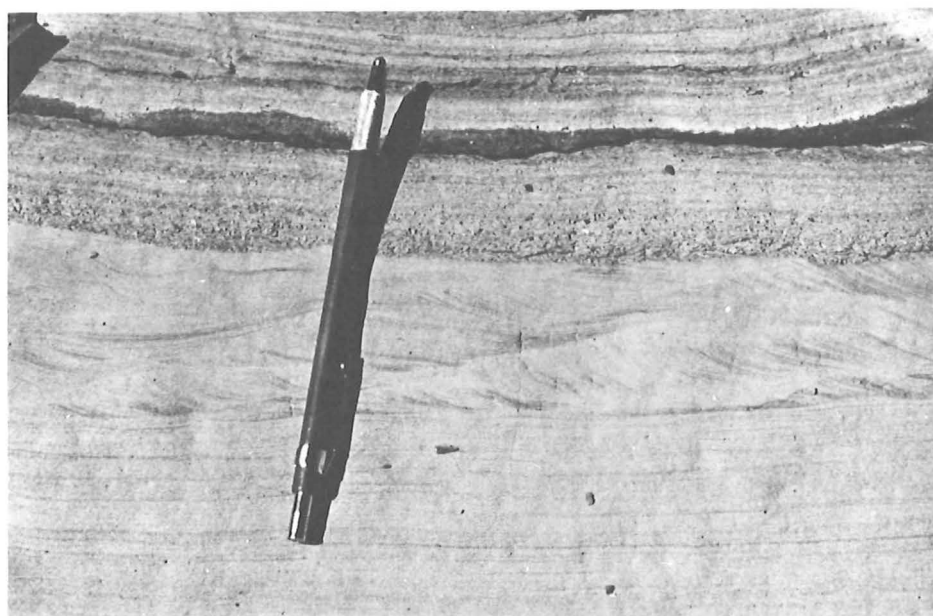
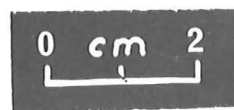
Compound sand bed; note the abundance of parallel lamination and the climbing ripples.

Figure 3.11

Frequency graded and parallel laminated sandstone; note the floating granules in the upper laminated layers, the carbonaceous laminae, and the faint cross laminations in the basal coarse layer.

(Pencil points up)





(horizontal and inclined internal stratification, well sorted sandstones). However, if the internally bedded sandstones and conglomerates were traction deposits, one would expect them to have sharp, erosional contacts with structureless beds. Figures 3.7 and 3.8 show that the contacts are not erosional and that the internally bedded sandstones and conglomerates genetically belong with the structureless conglomerates. Thus, the transition from massive to bedded conglomerate to laminated sandstone reflects a single mass flow whose flow regime is changing over time. Similar internally bedded sandstones and conglomerates have been described by Lewis et al (1980). The sudden change from conglomerate to sandstone deposition (fig 3.7) may reflect a change in mass flow regime or a sudden shortage of conglomerate.

The lower section of facies II also contains thin beds (5-30cm thick) which generally lack conglomerate. Thus sand beds are parallel laminated, rippled and have basal deposits which are either parallel laminated, well sorted, very fine grained sand (fig 3.12) or poorly sorted, structureless to parallel laminated, graded, coarse to very fine grained sand (figs 3.10 and 3.11). The thin sandstones increase in abundance upwards so that in the upper section they are the dominant sandstone type. The origin of these beds will be discussed in the upper section description.

#### b) Contact on Facies I.

The transition from facies I to facies II is rapid and for correlative purposes the contact is picked on the first appearance of mudstone. Figure 3.13 shows that the change from thick conglomerate beds to alternating sandstones and mudstones, although obscured, takes place over an interval of

less than 5 meters. This sudden decrease in maximum clast size and bed thickness suggests a relatively sharp decline in sedimentation energy. The sudden appearance of mudstone may be due to either less erosion between coarse depositional events or an increase in the time interval between coarse depositional events.

### c) The Upper Section.

The upper part of facies II contains mudstones, and thick (1m) sandstone but is characterized by the dominance of thin (5-25cm) sandstone beds. Percent mudstone increases up section so that mudstone begins to dominate over sandstone. Conglomerates are rare.

Texturally, the thin sandstones are moderately well to well sorted, very fine to fine grained arenites with occasional mud rip up clasts in the basal few centimeters. The dominant sedimentary structures are parallel lamination, ripples, and cross lamination (see fig 3.12). The bases of the thin sandstone beds are sharp and the tops are either transitional (with interlaminated silt and mud) or sharp (fig 3.14). Occasionally, thin sandstones are massive and rich in mud rip up clasts. Geometrically, the thin sands have a higher length/width ratio than the thick (1m) sandstones. When sandstone beds become very thin ( $\leq 5\text{cm}$ ) the beds may have transitional tops and bases with laminated silt.

The depositional mechanism for the thin sandstone beds could be either traction currents, mass flows, or both. Figure 3.15 is an idealized example of a thin sandstone whose features could be easily explained by traction currents: basal scouring followed by deposition in the lower flow regime giving alternating bands of parallel laminations and ripples.

Figure 3.12

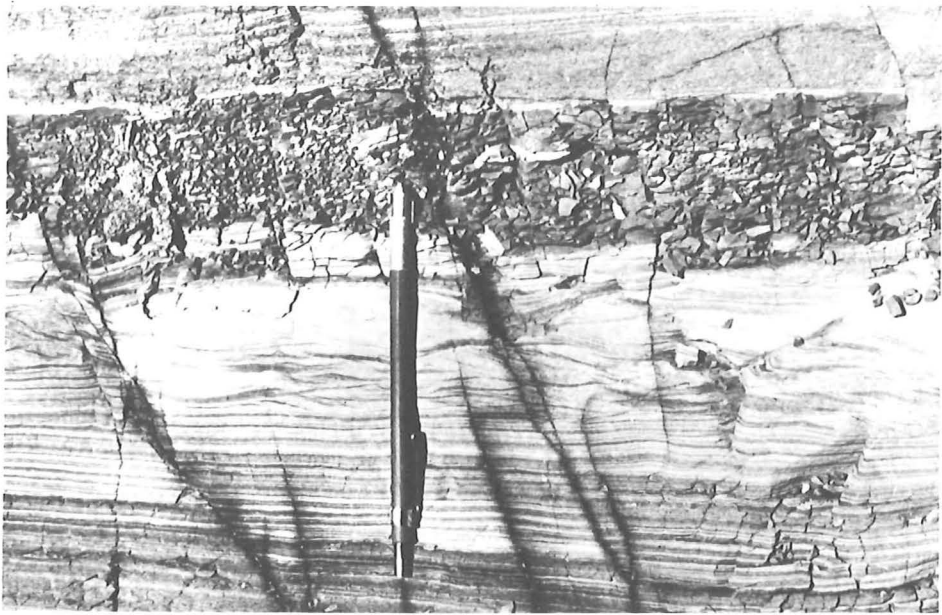
Very common parallel laminated and rippled sand; note the interlaminated sand and silt at the top of the bed.

Figure 3.14

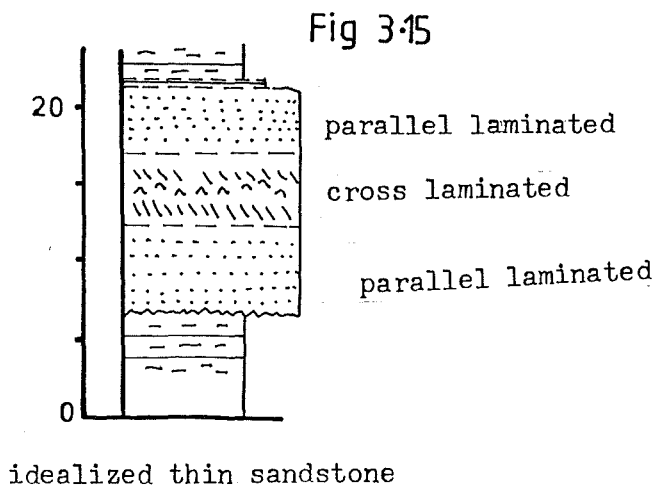
Thinner sandstones, facies II; note the transitional tops and interlaminated sand and silt in the middle of the beds.

Figure 3.17

Sandstone packages surrounded by thick mudstones: facies III.



The top centimeter grades quickly into laminated silt as the current wanes.



However, sandstones similar to fig 3.15 may also be interpreted as a BCD turbidite or (fig 3.10 and 3.11) as AB or ABC turbidites (Bouma 1972, Mutti and Ricci Lucchi 1978, Walker 1979). Lewis et al (1980) and Van der Lingen and Pettinga (1980) have described similar sandstones as mass flow deposits. Thus, mass flow mechanisms may be responsible for most of the deposition. However, the presence of inter-laminated sand and silt (fig 3.14) suggest a current which is waxing and waning quite rapidly; such energy fluctuations are more common in traction currents than mass flows. Thus, at least some of the sandstones appear to be traction deposits.

The mudstones lying between the sandstones commonly contain laminations of silt (fig 3.14). These deposits represent quiet background sedimentation of mud from suspension and the reworking of silts and muds by weak currents.

The thick sandstones of the upper section occur in sets of two or three (fig 3.16a). Generally these thick beds have sharp bases, are parallel laminated, and grade up into

laminated silt and mud. The bed geometry is lenticular with low length/width ratios. Similar lithologies have been interpreted as mass flow deposits by Van der Lingen and Pettinga (1980).

Figure 3.16a shows a measured section through the upper section of facies II. The sequence consists of alternating thin sandstones and mudstones interrupted by thick sandstones. The occurrence of thick sandstones in groups and the thick sandstones' channel-like geometry suggests a channel-interchannel system. However, the detailed section (fig 3.16b) shows no clear coarsening of fining upward sequences as described by Ricci-Lucchi (1975) or Walker (1979). The channels, therefore, may represent avenues of sediment bypass rather than distributary channels on depositional lobes.

### 3. Facies III

Facies III contains alternating sandstones, mudstones, and siltstones and is characterized by thick mudstone dominated units broken randomly by local horizons of interbedded sandstones and mudstones (fig 3.17). The interbedded sandstone/mudstone horizons range from 10 to 30m thick and are laterally discontinuous. Each horizon contains both thick (1m) and thin (5-25cm) sandstones identical to those described in Facies II. The mud dominated sequences consist of mudstone and laminated siltstone with occasional thin (5-25cm) sandstones. The mudstones, although occasionally structureless, always contained some silt; therefore no true shales were recognized. By virtue of the abundant mudstone, this facies is poorly exposed.

The mudstones represent quiet sedimentation which probably spans most of the time represented by the Upper Winterton Fm.

The abundance of mudstone but the absence of shale suggests the site of deposition is not a great distance from the shoreline. The occasional solitary sandstone or sandstone rich horizon represents bursts of rapid sedimentation. The sandstone rich horizons may be crudely symmetrical with thin bedded sands at the base, thick bedded sands in the middle, and thin bedded sands at the top (fig 3.17). The sand rich horizons may represent sand rich lobes or channels. The solitary sandstones may be unrelated to the sand rich horizons and may represent storm induced deposition.

#### 4. Facies IV

Facies IV occurs at the top of the Upper Winterton Fm and contains abundant mudstone with laminated siltstone and occasional thin sandstones. The general outcrop of facies IV appears structureless, but stream sections reveal abundant sedimentary structures in the siltstones (fig 3.18). The sandstones are similar to the thin and very thin sandstones in facies II. There are also turbidite-like beds (fig 3.19) consisting of a poorly sorted, muddy, basal deposit overlain sharply by interlaminated very fine grained sands and silts. The basal deposit clasts are Aucellina, Inoceramus, and gastropod fossil fragments and pebble sized mud clasts. These beds might be interpreted as AB or AD turbidites, however, the presence of floating, unbroken Aucellina shells in the basal deposit suggests the matrix was sufficiently cohesive to support the fossil clasts. The Aucellina shells are very delicate and one would expect them to be badly broken if a turbidity current was the transporting mechanism. A debris flow mechanism is therefore preferred.

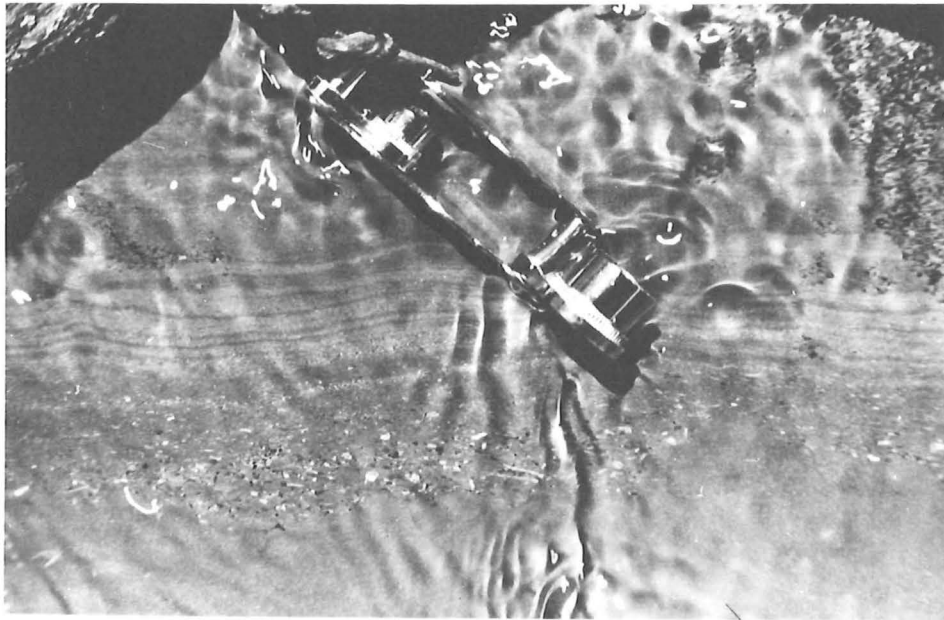
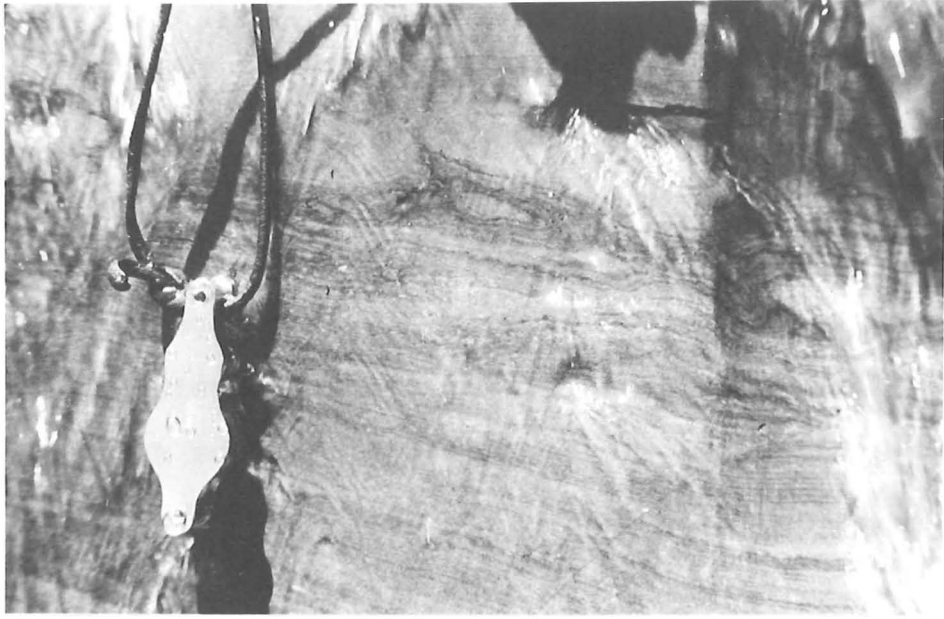


Figure 3.18

laminated silt in mudstone: facies IV

Figure 3.19

thin debris flow rich in fossil fragments and  
rip up clasts overlain by interlaminated sand  
and silt.



The increase in percent mudstone from facies III to IV and the appearance of muddy debris flows in facies IV suggests either that the site of deposition was becoming increasingly distant from the sediment source or that the supply of sand sized sediment was declining. Like facies III, the prevailing condition was quiet deposition interrupted by sudden bursts of sedimentation. No true shales are recognized, which suggests the water depth was not significantly greater than facies III.

## 5. Geologic Development

Following a period of erosion, the Upper Winterton Fm was deposited in two phases: an initial channel fill phase and a subsequent basin fill phase.

The preceding erosional period cut a relatively deep submarine channel. Modern submarine channels tend to cut into platforms or relatively stable highs (Whitaker, 1974); the very presence of a significant submarine channel suggests that the overall setting was on or near a high rather than in a large basin. Present day active continental margins contain many localized basins bordering rising highs (Seely 1979, Howell et al 1980). Thus, the channel may have cut into a previously developed small perched basin; this would help explain the subsequent deposition of the Upper Winterton Fm.

During the first phase of Upper Winterton deposition, the submarine channel was filled with conglomerate and sandstone. The absence of any mudstone and the great thickness of conglomerate beds suggests the channel filled rapidly. Modern submarine canyons grow and develop during periods of coarse sediment influx (Normark 1974); canyons decay and are buried when the coarse sediment supply declines or moves away

(Normark 1974, Herzer and Lewis, 1979). If the filling of the Upper Winterton channel was due to a loss of sediment supply, one would expect the channel fill to consist of a coarse lag deposit overlain by mudstones which drape over the channel rims (Hoyt 1959, Herzer and Lewis 1979). However, the actual channel fill (facies I) contains entirely coarse material. Most documented examples of coarse channel fills are from shallow (<100m deep) channels (see Whitaker, 1974, Table 1); deep (>200m) ancient channels filled mostly by coarse material such as the Markey Gorge Canyon (Oligocene, California) or the Calabria Canyon (Mio-Pliocene, Italy) (Whitaker, 1974) are associated with concurrent tectonism. Thus, the change from erosion to the infilling of the submarine channel by facies I is better explained by local base level changes produced by tectonism rather than a loss of sediment supply.

The second phase of deposition began as the submarine channel was buried and sediment spread out over a wider area. The localized nature of the basin is suggested by the rapid thinning of the Upper Winterton towards Middelhurst Station (fig 3.1). Note, however, that facies I, II and III are thin but do not pinch out as the Upper Winterton Fm thins toward Middelhurst Station. This sedimentary drape of the Upper Winterton on highs suggests the formation as a whole occupies a subsiding basin (fig 3.20a) rather than a large channel (fig 3.20b).

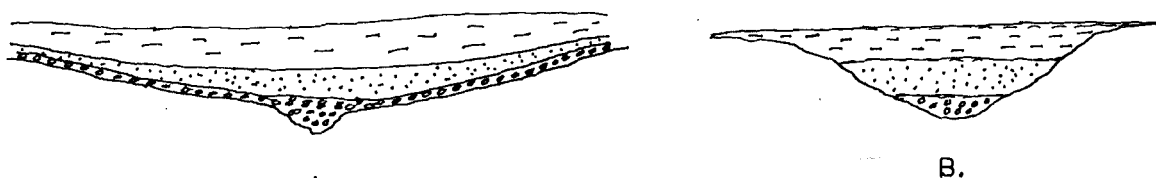


Fig 3-20

diagrammatic sketch of two types  
of small basin fill

### a) The Origin of the Fining Upwards Sequence

The sequence from facies I to facies IV comprises a fining upward succession from conglomerates at the base to mudstones at the top. Although percent mudstone increases, no shales ever appear; the sandstones are abundant in the middle of the succession and are dominantly one type (fine to very fine grained).

This fining upward sequence may be explained by eustatic sea level changes. A sea level lowstand may have produced the erosion of the Upper Winterton submarine channel and a steadily rising and transgressive sea may cause a fining upwards sequence. However, the absence of true shales up section may suggest that the distance between the site of deposition and the shoreline is not significantly increasing. This is supported by the presence of unbroken Inoceramus and Aucellina shells (in facies II, III and IV) which are shelf fossils (I. Speden pers comm) and could not have survived a long transport intact due to their fragile shells. It may be argued that eustatic sea level changes of 40-60m would be sufficient to produce a fining upwards sequence and that such a small shift in sea level may not be detectable using redeposited fossils. However, as explained above, the channel burial sequence (facies I) does not show symptoms of a starved canyon; rather, a channel which has been buried by an influx of sediment. Thus, although sea level was apparently on the rise during the Albian (Vail et al 1977), eustatic changes do not appear to be the major cause of the fining upwards sequence.

Another possibility is to produce the fining upwards sequence by reducing sediment supply. This may be accomplished by an updip delta whose distributary migrates towards

and then away from the Mt. Lookout area, producing a fining upwards succession. The presence of the Upper Winterton submarine channel suggests an updip river system, for these two features are presently commonly associated (ie. Niger delta and channels, Mississippi River and channel, Congo River and gorge, Hudson River and canyon, etc). The presence of an updip delta also helps explain the overwhelming volume of compositionally and texturally identical, fine to very fine grained sands. However, a shifting distributary should produce a fine grained channel fill, reflecting starvation of the channel, similar to the eustatic sea level rise. Since the channel fill and the overlying facies II represent abundant coarse sediment supply, the delta model alone does not satisfactorily explain the fining upward sequence.

Filling the Upper Winterton submarine channel and basin with an influx of coarse sediment could be explained by a submarine fan system. In this model coarse sediments lap back up the channel during a period of shelf erosion (fig 3.21)

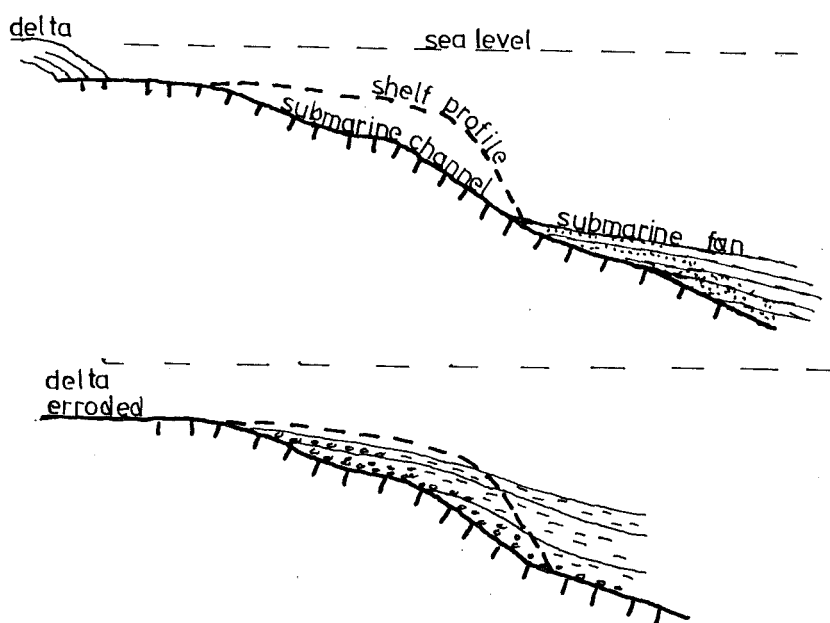


Fig 3.21

diagrammatic cross section of  
marine onlap in a submarine channel

and fill the channel with coarse then gradually fine sediments. There are some problems with this model, however; if the restrictiveness of the Upper Winterton Fm were due to its being a submarine canyon fill, the facies would pinch out towards the highs (fig 3.20b). The facies, however, appear draped over the highs. The fan/delta model would also predict a significant thickening of the Upper Winterton Fm down paleoslope; the Upper Winterton, however, does not appear to thicken significantly down dip (see chapter 7).

Thus, both the delta and submarine fan systems may explain fining upwards sequences, but neither model appears directly applicable to the Upper Winterton Fm. The Upper Winterton is therefore interpreted as a small basin fill independent of any large sediment pod or wedge. The change from erosion to deposition is attributed to base level changes due to local tectonism. The conglomerates, therefore, represent accelerated erosion following tectonic movements. The sudden drop in percent conglomerate at the end of facies I and the dominance of very fine grained sand in facies II, reflect the region coming into equilibrium with the new configuration. The source of the very fine grained sand is probably a river system somewhere up dip. The gradual fading of sandstone and increased abundance of mud may be due to a lower supply of sand brought in by the updip river or a migration of the river away from the Upper Winterton basin. The tectonic-small basin hypothesis thus complements rather than excludes the delta model.

## THE CASTLE CREEK CONGLOMERATE

### 1. General Facies Distribution

The Castle Creek Conglomerate has been subdivided into two units: a lower sandstone with occasional interbedded mudstone, and an upper sandstone with interbedded conglomerate. In fig 3.22 the facies appear to drape on the high to the NW rather than onlap upon the high; also the unit appears to thicken and thin rapidly.

The lower unit contains well sorted, very fine grained sandstone which usually looks massive but is faintly parallel laminated in stream sections where the surface is clean. Occasionally there are lenticular bodies of interlaminated silt and mud. The lower sandstone may also contain randomly spaced, very well rounded, and polished pebbles which float in the sandstone.

The upper unit contains interbedded sandstone and pebbly conglomerate. The sandstones are well sorted and very fine grained. The conglomerates consist of well rounded and polished pebbles occurring in matrix supported beds, small lenses, or pebble laminae. The pebbles consist of chert, quartzite, well indurated sandstone, and igneous rocks. The presence of floating pebbles in the lower unit and matrix supported conglomerate in the upper unit supports a mass flow origin for this unit. The overall lack of mudstone suggests the unit was relatively rapidly emplaced.

### 2. Geologic Development

A period of erosion followed the deposition of the Upper Winterton Fm. The Upper Winterton thins from 370m to 0m thick over a distance of one kilometer in the area .5 to 1 km



# CASTLE CREEK CONGLOMERATE FACIES

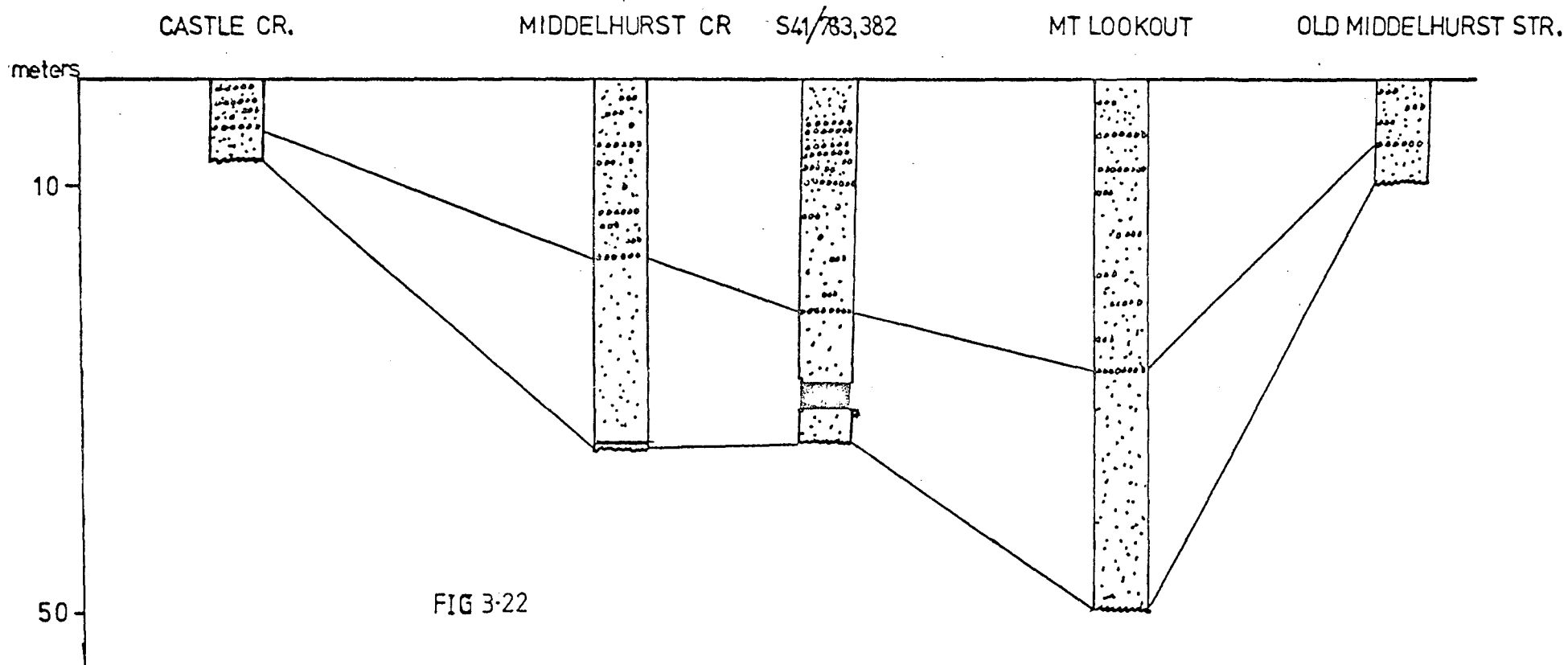


FIG 3-22

SE of Middelhurst Station. Such a pinchout requires a 25° slope, which seems unusually steep for marine conditions. The Upper Winterton Fm is more likely faulted out; unfortunately the trend of the fault is obscured by poor exposure. The consequence is, however, that the erosional period, which followed the deposition of the Upper Winterton Fm, was accompanied by faulting within the basin. The erosion preceding the Castle Creek Conglomerate was apparently not as severe as the erosion preceding the Upper Winterton Fm, for no deep channels are present. The same well sorted, very fine grained sandstones present throughout the Upper Winterton Fm occur in the Castle Creek Conglomerate and probably originate from the same up slope source. The Castle Creek Conglomerate is strikingly similar to some of the basal sandstone-conglomerate units of the Upper Winterton Fm (see fig 3.4) and like the Upper Winterton, the Castle Creek Conglomerate was also deposited following a period of erosion and tectonism. Thus, the Castle Creek Conglomerate is inferred to represent the coarse basal facies of another fining upwards cycle, similar to the Upper Winterton. The geologic history of the Castle Creek Conglomerate, therefore, began with coarse deposition in response to tectonism on an erosional surface. Sedimentation continued, producing a fining upwards sequence of unknown thickness. Deposition changed to erosion following tectonism and most of the fining upwards cycle was removed, leaving only patches of the basal coarse facies (i.e. the Castle Creek Conglomerate) preserved.

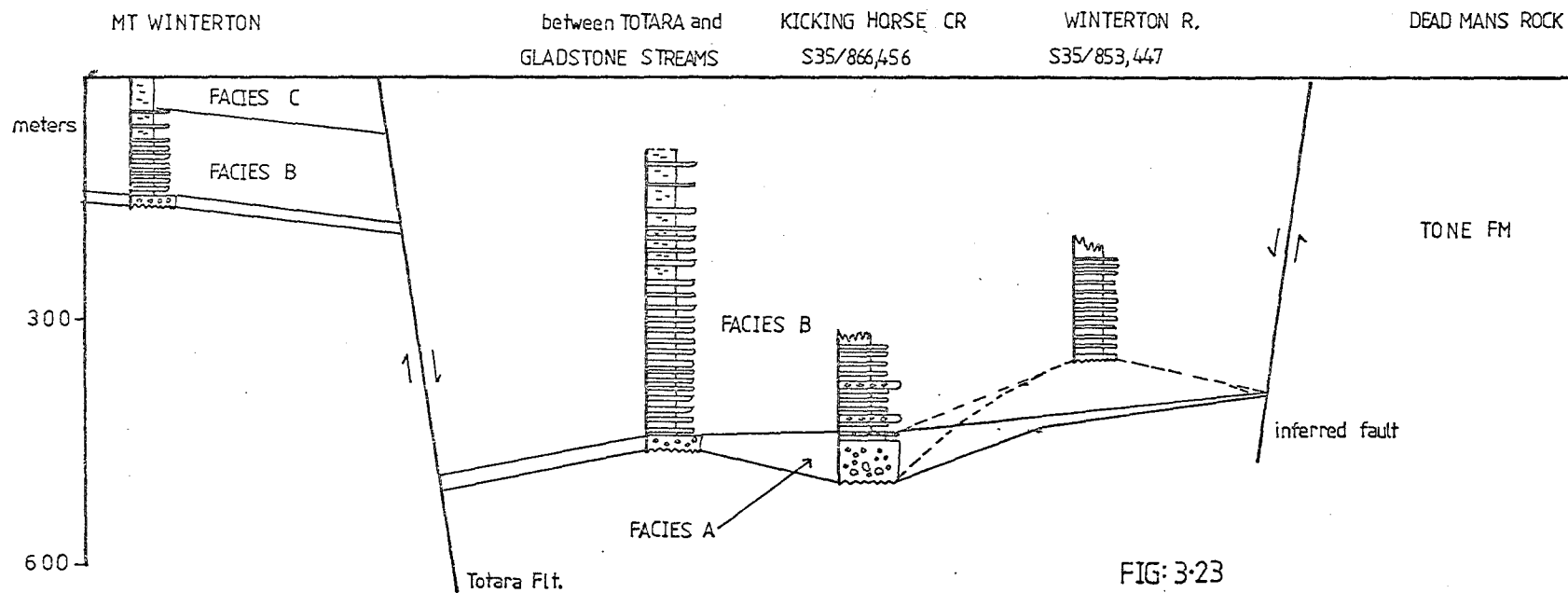
THE LOWER WINTERTON FM

The Lower Winterton Fm is similar to the Upper Winterton Fm but is more complicated and not as extensively preserved. Generally, the Lower Winterton is a fining upwards sequence consisting of three facies: a) a basal conglomerate, b) a sand rich flysch like unit, and c) a mud rich flysch like unit. Figure 3.23 shows that the thickness of the Lower Winterton Fm is influenced by the Totara Fault.

1. Facies A.

The basal facies contains interbedded conglomerates and sandstones. The conglomerates can be distinguished from the Upper Winterton conglomerates by the presence of muddy matrix. Crudely, facies A has a thick (5-50m) basal muddy or sandy matrixed, matrix or clast supported, conglomerate comprising boulder to pebble sized clasts. However, at S35/872,457 and S35/853,447 the base of the Lower Winterton is sandstone. The basal unit is overlain by alternating sandstones and conglomerates; these lithologies occur singularly or together in one bed (fig 3.24). The sandstone and sandstone/pebbly conglomerate beds are usually 10cm to 50cm thick but may exceed one meter; the cobbly-pebbly conglomerate beds commonly are 1 meter or thicker. The sandstone beds are generally parallel laminated. The pebbly conglomerate/sandstone beds (fig 3.24) evolve from massive, poorly sorted, pebble-granule conglomerate at the base to laminated granule-sandy conglomerate to parallel laminated sandstone with laminae of granule to coarse sand sized clasts. The sandstones and conglomerates of facies A are similar to the sandstones and conglomerates in the Upper Winterton Fm and are likewise interpreted as mass flow deposits.

# DIAGRAMMATIC SKETCH of LOWER WINTERTON FM FACIES



The basal facies thickens significantly in the area around S35/867,457 (above Kicking Horse Cr) but is absent at S35/853,447 in the Winterton River. This pinching out over a short distance suggests the facies occupies a channel (fig 3.23). Thus, facies A resembles facies I both in geometry and lithology, although the Lower Winterton channel is not as deep as the Upper Winterton submarine channel.

## 2. Facies B.

The middle facies contains interbedded sandstones, siltstones, mudstones, and conglomerate. Overall, this is a sand dominated, flysch-like sequence but more conglomerate is present than in facies II or III of the Upper Winterton Fm. Texturally, the sandstones are moderately to well sorted, fine to very fine grained arenites with occasional granule or coarse sand sized clasts. The conglomerates are poorly sorted, pebble to cobble sized, structureless, and clast supported. Beds are generally less than 1m thick, but conglomerates may exceed one meter in thickness. In figure 3.25 (composite section measured at S35/860,439) the interbedded sandstones, siltstones, and mudstones have a similar style to facies II sandstones and likewise are interpreted as predominantly mass flow deposits.

In figure 3.23 deposition of facies B and movement along the Totara Fault appear to be concurrent. Facies B rocks also contain small penecontemporaneous growth faults (fig 3.26), suggesting fault or gravity induced tectonism. Thus, unlike the Upper Winterton Fm which appears to be a deposit between pulses of tectonism, the Lower Winterton Fm was deposited during tectonic activity. Consequently, the Lower Winterton Fm has greater thickness variations (due to fault movement)

and is more conglomeratic.

### 3. Facies C.

The Upper mud dominated facies is recognized with certainty only to the west of the Totara Fault. Facies C contains interbedded sandstones, siltstones, mudstones and rare conglomerates but generally is a mud dominated flysch-like sequence. Sandstones are dominantly thin bedded (5-10cm) and parallel laminated; thicker sandstones occur with conglomerates in lenticular horizons. The siltstones occur interlaminated with sandstone at the top of sandstone beds or as individual parallel laminated beds in mudstone. The top of facies C is commonly a massive mudstone up to 15 meters thick. The presence of pebbly-cobbly conglomerates in facies C suggests coarse sedimentation is periodically triggered by some mechanism which was not present during facies III or IV of the Upper Winterton Fm.

### 4. Geologic Development

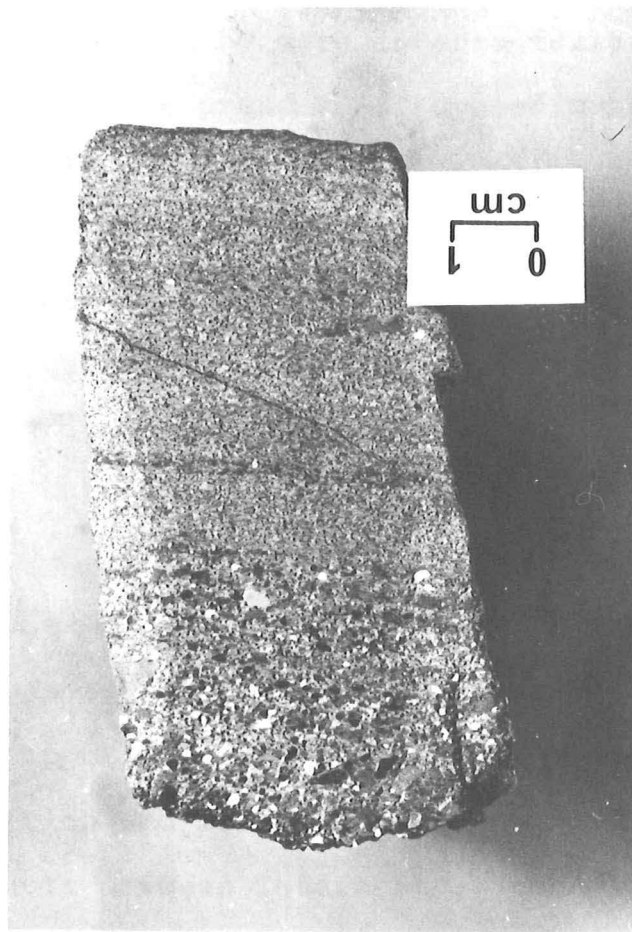
The Lower Winterton Fm began with a period of erosion, during which a shallow channel was eroded out of the substratum. The base level of the area readjusted due to faulting and sedimentation was re-established. Deposition began with the rapid burial of the channel, followed by a more widespread, sand rich, flysch-like sequence. Sedimentation was at least partly controlled by faulting. The last phase of deposition was relatively quiet, but interrupted periodically by coarse, rapid sedimentation which may reflect ongoing tectonism in the adjacent region. Local faulting continued, causing erosion of the Lower Winterton and complete removal of the formation from the area between Kicking Horse Cr

Figure 3.24

Massive to parallel laminated, granule to pebbly conglomerate passing upwards into parallel laminated sandstone; note floating mud clasts in the upper part of the sandstone.

Figure 3.26

Small growth fault; note how the fault dies rapidly upwards.





and Dead-Mans rock.

In general, the Lower Winterton Fm appears to be accompanied and succeeded by more intense faulting than the Upper Winterton Fm. The presence of synsedimentary faults in the Lower Winterton and the severe erosion following the deposition of the Lower Winterton support the hypothesis that the major control on sedimentation and the resultant fining upwards sequences is tectonism rather than a sedimentary distributary system.

#### THE GLADSTONE FM

The Gladstone Fm is not well exposed or preserved and a portion of it appears allochthonous. Southwest of the Totara fault along the upper Winterton River, the Gladstone Fm is relatively sand rich and in part allochthonous. Northeast of the Totara Fault between Totara Str., the middle Winterton River and Kicking Horse Cr., the Gladstone Fm is relatively mud rich and occurs in place. On Map 1 the southwest section appears thicker than the northeast section, but this may be due to erosion after the deposition of the Gladstone Fm. Although there are structural differences between these two sections of the Gladstone Fm, both the southwest and northeast sections appear to be fining upward sequences.

#### 1. The Northeast Section

The northeast section is in place and so the sedimentary succession is easier to establish. In figure 3.28, the fining upwards sequence described in the type area (Chapter 2) is compared to a similar sequence above Kicking Horse Creek. Both units begin with basal mudstones, contain thick lower sandstones and grade up into mud dominated flysch-like

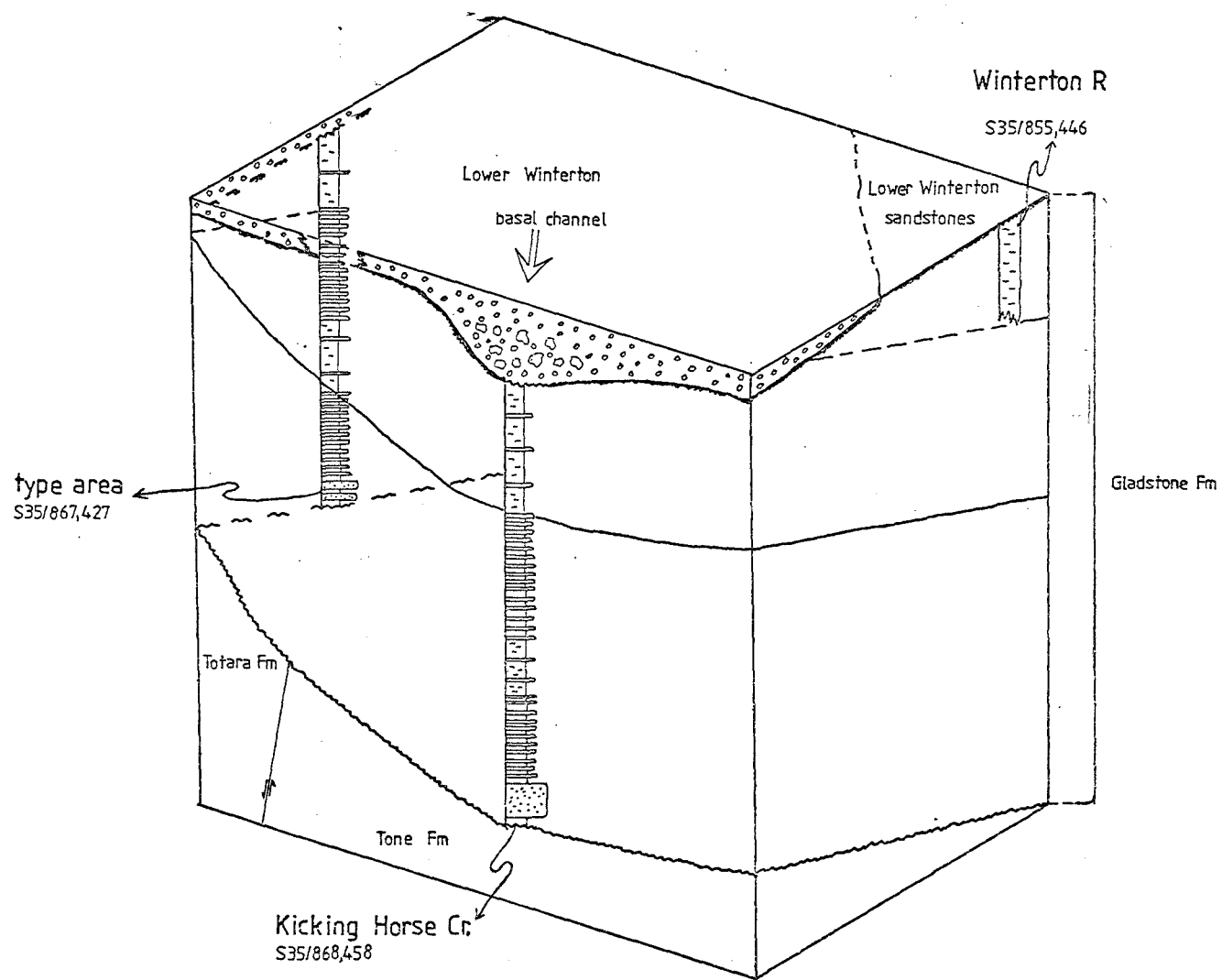


Fig 3-28  
diagrammatic sketch of Gladstone Fm lithofacies

sequences. In Totara Stream the basal mudstone is replaced by 20 m<sup>+</sup> of pebbly-cobbly conglomerate which appears nowhere else in the northeast section and probably represents a small channel fill. Thus, the base of the Gladstone does not have the widespread coarse basal deposits that the Lower and Upper Winterton Formations contain. The conglomerates which do occur apparently fill channels; however, these channels are very shallow compared to the overlying formation. Both sections in fig 3.28 have been eroded subsequent to their deposition and therefore do not represent the original formation thickness. In the lower Winterton River the Gladstone Fm is entirely massive mudstone at least 100 m thick; a similar thickness of mudstone possibly originally overlaid the sections in fig 3.28.

## 2. The Southwest Section

The southwest section is allochthonous along the Winterton River from S35/863,425 to at least 850,400. However, the thickest sand beds and the highest percent sand in the section occur near the contact (fig 2.6) at S35/862, 417. The Gladstone Fm is a sand dominated flysch-like sequence on the eastern bank of the Winterton R. and becomes mud rich on the western bank. As shown in the reference section (fig 2.5) the fining upwards succession is not nearly as systematic as the overlying units. Relatively sand rich flysch-like units interfinger with and are enclosed by mud rich units and can be seen on the west bank of the Winterton River at S35/862, 417. In the uppermost Winterton R. at S42/844,386 another localized basal conglomerate rests directly on the contact. This conglomerate contains a mud matrix and floating pebbles, cobbles, and small boulders; the conglomerate is overlain by

a sequence of interbedded sandstones and sandy conglomerates. The entire sequence in the uppermost Winterton River is relatively sand rich; no fining upwards succession is apparent.

Some generalizations can be made about the lithologies in the Gladstone Fm. The few paleocurrent directions obtained all indicate a general SW to NE trend; the percent sand in the Gladstone Fm declines from SW to NE. The Gladstone Fm apparently fines upward in the NE, but fining upwards is not apparent in the far SW. The fining upward nature of the sequence is not systematic, for there are vertical sections containing alternating horizons of muddy and sandy flysch-like rocks. Basal conglomerates are less common, thin, and occupy small channels.

Compared to the overlying Lower and Upper Winterton Formations, the basal channels of the Gladstone Fm are very shallow, suggesting that erosion preceding the deposition of the Gladstone Fm was not severe. This suggests that the Gladstone Fm was deposited in an overall environment which lay further from a platform, shelf, or high<sup>er</sup> than the Lower or Upper Winterton Formations. The lower percent conglomerate in the Gladstone Fm compared to overlying formations may also be due to a more distal environment. The allochthonous nature of part of the Gladstone Fm suggests deposition on a slope. The sandstones of the Gladstone Fm are identical to the sands of the overlying formations. Sandstone beds in the Gladstone Fm also have the same morphology and sedimentary structures as the overlying Lower and Upper Winterton Fms. and are therefore also interpreted as mass flow deposits. The fining upwards character of the Gladstone Fm is not readily apparent at some localities; however, the presence of thick (100 m<sup>+</sup>) structureless mudstones compared to 100-150 m sections

of alternating sandstones and mudstones (fig 3.28) in the northeast section suggests that the original Gladstone Fm had a higher mud percentage than the overlying Lower and Upper Winterton Formations. The higher mud percentage of the Gladstone Fm may be explained by deposition in a more distal environment.

### 3. Geologic Development

The Gladstone Fm was deposited after a period of moderate erosion in an environment with a metastable slope. The deposition began with conglomerate filling the channels and mud settling out over the interchannel areas. The second stage of deposition produced alternating horizons of sandstone and mudstone rich flysch-like sequences. Presumably, the third stage of deposition produced thick, structureless mudstones. Shortly after deposition, the Gladstone Fm was tilted, faulted, and part of it slid downslope, causing folding. Erosion followed deformation, producing a relatively deep submarine channel.

### SYNTHESIS

The Gladstone Fm, Lower Winterton Fm, Upper Winterton Fm and Castle Creek Conglomerate have similar paleocurrent directions, lithologies, sedimentation processes, and ages. Each formation contains: 1) an initial period of erosion, 2) a change from erosion to deposition, 3) rapid burial of channels by conglomerates, 4) basin sedimentation by a fining upward flysch-like sequence, and 5) a final period of faulting, tilting, and erosion.

Any interpretation must consider the following observations:

1. Each cycle contains large volumes of compositionally and texturally identical sandstone.
2. The conglomerate compositions are dominated by sedimentary clasts, but the lithic component of the sandstones is dominated by igneous clasts. (Chapter 4).
3. The severity of channel downcutting (during erosional periods) increases from the Gladstone Fm to the Upper Winterton Fm.
4. Where evident, sedimentary facies drape rather than lap up on highs.
5. The cycles are unconformable and the degree of discordance between each cycle decreases upward.
6. The dominant sedimentation mechanisms are mass flow and suspension settling.
7. The rate of deposition, maximum clast size, and percent sand all decrease upwards in each cycle.
8. The evolution of each cycle from erosion to deposition to uplift and erosion is controlled by tectonism.

The simplest explanation for the abundance of very fine grained sand is to have a river or delta updip which supplies virtually only that lithotype. The abundance of Torlesse-like and less deformed sandstone clasts in the conglomerates suggests a significant proportion of the conglomerates are locally derived, perhaps between the shoreline and the site of deposition. This suggests that there is local relief from which coarse material is eroded. The increase in basal channel depths from the Gladstone Fm to the Upper Winterton Fm suggests the site of deposition becomes increasing proximal to a platform, rising high, or shelf over time. The decrease in the structural discordance between formations over time, synsedimentary faulting, and the complete removal of the

lower two cycles from some localities indicate that sedimentation took place in a tectonically active basin. The change in sedimentation rate, and lithologies is thus primarily tectonically controlled. The fining upwards sequences apparently reflect pulses of tectonic activity in and around the basin. The presence of mass flow depositional mechanisms is consistent with the interpretation of the cycles as marine basin deposits and the rapid thinning of the Upper Winterton Fm and Castle Creek Conglomerate towards the NW suggest the basin of deposition is small.

#### THE TONE FM

The Tone Fm crops out over a somewhat elongate area between the Awatere Fault and the Inland Kaikoura Range from Muller Station to Awapiri Station. The formation appears uniform; no marker horizons have been found so no overall stratigraphic succession has been established.

The Tone Fm has three general lithotypes: a) thick massive sandstones, b) relatively thicker bedded sandstones with interbedded mudstones and c) relatively thin bedded alternating sandstones and mudstones. The thick (20m<sup>+</sup>) sandstones are lenticular, have sharp bases and tops and are usually well jointed and fractured. Although these sandstones appear massive, hand specimens do show fossil wood rich laminae. The thick sandstones are well sorted and very fine grained; no coarse sand or conglomerate was found. Lithotype B contains 10-70cm thick sandstones interbedded with 5-15cm thick mudstones. Although sedimentary structures are rare in the field, polished sections of the sandstones show that the sand beds are structureless, parallel laminated, and rippled. Individual beds in more deformed places had sharp

bases and tops, but in less deformed areas beds contained sharp bases and gradational tops. Lithotype C contains 5-20cm beds of sandstone and mudstone. Occasionally there were 50-60cm mudstone beds, but no mudstone facies was ever recognized; the Tone Fm on the whole is extremely sand rich. The thin sandstones were well sorted, very fine grained, structureless, and parallel laminated with sharp bases and abrupt or transitional tops. Moderately deformed lithotype C rocks were observed adjacent to more highly fractured lithotype A rocks, suggesting the two lithotypes behave differently mechanically.

The relation between these lithotypes is not always certain due to deformation and problems determining the "way up" when internal stratification is absent. Near the Tone River, two exposed blocks were measured. The coarsening upward sequence (fig 3.29a) is similar to distributary sequences described by <sup>Mutti and</sup> Ricci Lucchi (1978) and Walker (1979) for mid fan deposits. The interbedded lithofacies A and C (fig 3.29b) section did not display recognisable coarsening or fining upwards sequences adjacent to the thick sandstones. This suggests that lithotype C may represent a variety of subenvironments.

The currently popular explanations for the Tone Fm would be: submarine fan, delta, or fan delta. The sequence is probably not deltaic because of the absence of root, clay, or thick organic rich horizons and the lack of any apparent reworking of the distributaries by coastal processes (which is common in most modern deltas). The overall thickness of the Tone Fm, its monotonous succession, the facies, and the absence of any mudstone facies suggests deposition in a submarine distributary system, below wave base, and relatively continuous



sedimentation. The overall dominance of sand, and the abundance of thick channel sands suggest the Tone Fm lies in the midfan environment of <sup>Mutti and</sup> Ricci Lucchi (1978) and Walker (1979). The Tone Fm is also composed of essentially one sandstone type - very fine grained. The enormous volume of this sand suggests a large river is feeding the system from somewhere up dip. Because the updip deposits are not preserved, there is no accurate measurement of where the Tone Fm was deposited relative to the shoreline. The Tone formation is thick and therefore was deposited basinward of any hinge controlling the basin. If the Tone Fm is part of a fan delta system, the controlling hinge would lie up dip from the delta and the Tone Fm may be a shelf deposit. If the basin hinge is the edge of the continental shelf, the Tone Fm is probably a slope deposit.

#### RELATIONSHIP OF DEPOSITIONAL ENVIRONMENT AND STRATIGRAPHY

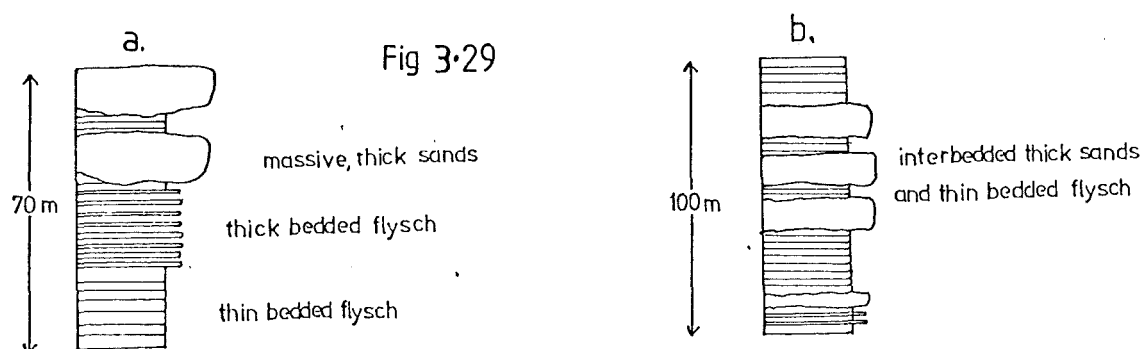
Although the Tone Fm and overlying marine units are distinct in sedimentary style, there is no evidence that they represent significantly different depositional environments.

The Tone Fm is a thick, widespread, sandy, mass flow deposited unit representing relatively continuous sedimentation in a well developed distributary system. The absence of conglomerate suggests that either the Tone Fm was deposited distally from a conglomerate source or that local erosion was insignificant during the deposition of the Tone Fm. The overlying marine, Motuan units are relatively thin, localized, mass flow deposited, fining upwards cycles representing sedimentation in ephemeral basins disrupted by uplift and erosion. The presence of deep channels filled with coarse conglomerate

and redeposited shelf fossils suggest a depositional environment at or near a platform.

Several authors have cited the sudden appearance of fossils in units overlying Torlesse-like rocks as evidence for a significant change in depositional environment. In the Middelhurst succession all fossils found are allochthonous and so are not reliable environmental indicators. It is true that Aucellina and Inoceramus shells are fragile and cannot have survived sustained abrasion, but the most which can be concluded from this is that the cyclic units were proximal to a platform upon which these bivalves lived. The lack of macrofossils in the Tone Fm is not a viable indication of water depth because many rapidly depositing sediment wedges are sparsely fossiliferous even in shallow water (i.e. Niger Delta, Mississippi Delta and Fan).

Thus, although a case can be made that the Tone Fm might be a more distal deposit from the shoreline relative to the cyclic units, there is no indication that this represents a significant change in environment because, in the evolution of basins, shelf or near shelf deposits commonly overlie slope environment deposits. The Middelhurst succession does suggest, however, a change in depositional style from the Tone Fm to the overlying cyclic units; this may reflect evolutionary changes in the style of basin development or in the intensity of tectonism.



## CHAPTER 4: COMPOSITION

### INTRODUCTION

The purpose of this chapter is: 1) to describe the detrital composition of the sandstones, mudstones, and conglomerates of the Middelhurst succession; 2) to examine whether there is any compositional change from Torlesse-like rocks to overlying rocks; 3) to examine the provenance and its implications for the overall tectonic setting; and 4) to discuss the paleoclimate and abrasion history of the sediments.

### DETRITAL COMPOSITIONS

#### 1. Sandstone Bulk Composition

The detrital composition of the sandstones was determined by counting 400 points from each slide using a Swift point counter. To assist in feldspar determination, two slides from each formation were stained using the technique of Hayes and Klugman (1959). Four samples from the Tone, Gladstone, Lower Winterton, Upper Winterton Formations, three from the Totara Fm, and two from the Castle Creek Conglomerate were point counted. The results are plotted in figure 4.1.

The results were retabulated into percentage quartz, lithics and feldspar according to the Folk et al (1970) classification (fig 4.2). The sandstones consistently contained between 10 and 15% quartz but displayed a wider range in feldspar (35-57%) and lithic (28-54%) components. As shown on fig 4.2, the values of the formations collectively

Fig:4.1 Point Count Results (expressed as percentages)

COMPONENTS	9269	9270	9250	9251	9252	9253	9254	9255	9256	9257	9258	9259	9260	9261	9262	9263	9264	9265	9266	9267	9268
quartz	10	6	9	6	14	11	9	12	15	7	6	10	9	12	6	7	11	11	9	10	10
plagioclase	32	31	—	—	40	—	—	35	34	—	—	27	—	32	—	—	—	43	—	—	36
alkalie feldspar	9	6	—	—	15	—	—	5	12	—	—	7	—	9	—	—	—	11	—	—	9
feldspar total	41	37	45	40	55	41	46	40	46	43	53	34	47	41	50	36	44	54	36	47	48
lithics	14	24	28	25	27	39	34	39	34	43	37	50	36	41	34	44	36	29	38	35	34
mica	tr	1	1	1	tr	2	0.5	1.0	0.5	0.5	0.5	0.5	2	0.5	2	3	1	2	3	3	3
heavy minerals	tr	tr	1	tr	1	tr	tr	0.5	tr	0.5	1	0.5	0.5	0.5	2	3	1	2	1	1	1
matrix	tr	2	1	1	1	7	10.5	8	5	8	2	5	6	3	4	7	7	1	13	4	4
calcite cement	35	30	15	28	tr	tr	tr	tr	tr	tr	1	tr	tr	tr	2	tr	tr	tr	tr	tr	tr
FOLK et al(1970) CLASSIFICATION																					
quartz	9	10	11	9	15	12	10	13	16	8	6	11	10	14	7	8	12	12	11	11	11
feldspar	57	55	54	57	57	45	52	44	48	46	55	35	51	43	55	42	48	55	43	51	51
lithics	34	35	34	34	28	43	38	43	36	46	39	54	39	43	37	50	40	33	46	38	38
CASTLE CR. CONG.		UPPER WINTERTON					LOWER WINTERTON					GLADSTONE					TOTARA			TONE	

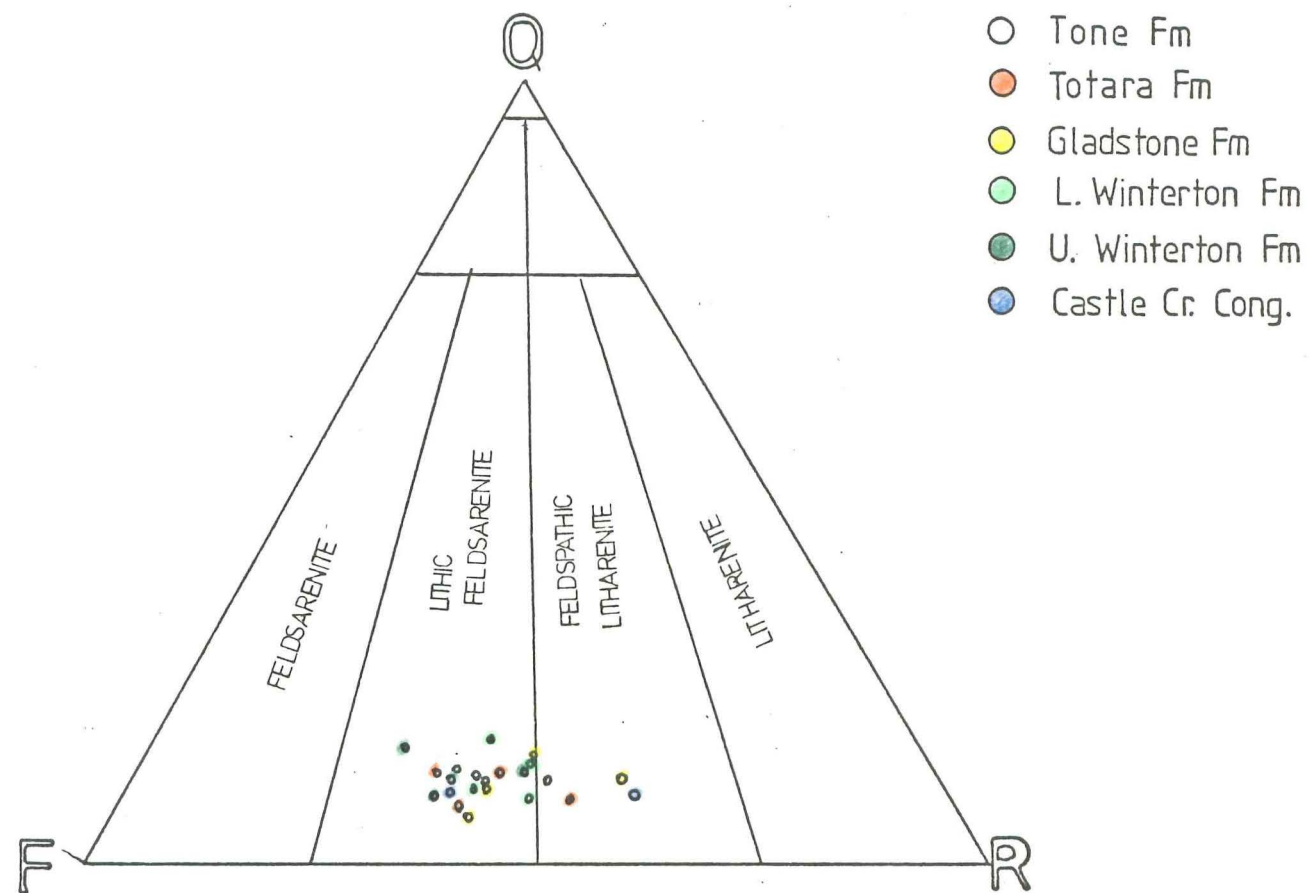


Fig 4.2

define a zone, but individual units are not differentiable within the zone. According to the Folk et al (1970) classification, these rocks would be mainly lithic feldsarenites and subordinately feldspathic litharenites.

Problems in point counting were caused by diagenesis. Many of the rock fragments were either too small, too flattened, or too altered to be recognizable, and separate counting of igneous, sedimentary, and metamorphic lithic clasts was attempted but the results were discarded. Hall (1963) and Challis (1965) have described these and similar rocks in Marlborough as having between 15% and 50% matrix; most of this "matrix" however is squashed rock fragments. True matrix, although difficult to distinguish at times, is generally between 5-10% of the rock.

The sandstones were almost entirely moderately well to well sorted, sub angular, very fine to fine grained, structureless and laminated arenites. The thin sections used for point counting were all rocks of this type. The size sorting of quartz and feldspar was generally good; lithic fragments, particularly sedimentary ones, had larger maximum grainsizes; heavy minerals tended to have smaller maximum sizes. This most likely reflects density differences among the grains. The lithic clasts were generally the best rounded constituents and the weathered feldspar appeared sub rounded while the relatively fresher grains were more sub angular.

A few of the sandstones had laminae which were only moderately sorted due to 0.5 mm grains in among the usual 0.1-0.2 mm sized grains. In some sandstones 0.5 to 1.0 mm clasts "floated" randomly in a very fine grained matrix. As described in Chapter 3, the basal facies of the Lower and

Upper Winterton Fms contained beds of poorly sorted, very fine to granule sized grains. Excluding the mud rip up clasts, the 0.5-1.0 mm size range appears to have a higher quartz/feldspar ratio than the fine to very fine size fraction. The concentration of feldspar in finer grain sizes has been reported by Odom et al (1976) and Basu (1976) and is attributed to the greater difficulty in breaking quartz down past the medium sand size range. This suggests that the duration of mechanical or chemical weathering of the Middelhurst succession sediments was relatively brief.

## 2. Sandstone Grain Morphology

### a) Quartz

Quartz grains ranged from subangular to rounded, suggesting that some of the grains may be primary while others are reworked. The grains generally are monocrystalline, clear, have uniform extinction, and a distinctively smooth crystal surface on the S.E.M. Occasionally, quartz grains have undulose extinction. Some grains contain linear trending inclusions, but microlites were not observed.

The fluid inclusions suggest that some of the quartz is of igneous-hydrothermal origin; the well rounded quartz implies that a portion of the grains are recycled sediments. The significance of undulatory extinction is uncertain (Blatt 1967) so there is no positive indication of a metamorphic source.

Mechanically, quartz grains were competent; there was no intercrystalline strain, fractures, or pressure solution in response to pressure. Chemically, quartz grains only rarely were corroded or contained overgrowths.

## b) Feldspar

Feldspar is the most abundant mineral in the sandstones. Alkali and plagioclase feldspars were identified by 2V, R.I., twinning, staining, and X.R.D....sanidine, microcline, anorthoclase, and albite were the principal alkali feldspars and together comprise less than 30% of the total feldspar. Plagioclase feldspars ranged from low Ca andesine to albite.

Alkali feldspars were mildly to severely weathered in the Middelhurst succession. Perthite and myrmekite grains clearly showed that the potassium feldspars were more susceptible to weathering (fig 4.3). On the other hand, well twinned microcline grains were both fresh and markedly weathered, suggesting that microcline originates from more than one source.

Plagioclase grains were also differentially weathered. Zoned plagioclase was preferentially weathered in the calcium rich interior and albite to andesine range grains varied from strongly weathered to quite fresh. Weathering differences may be a function of in situ processes (such as hydrothermal alteration) within one source, or the result of grains from different sources.

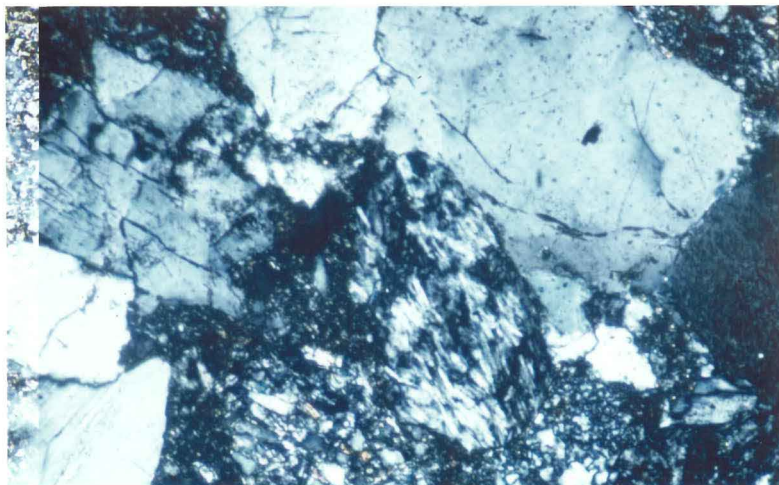
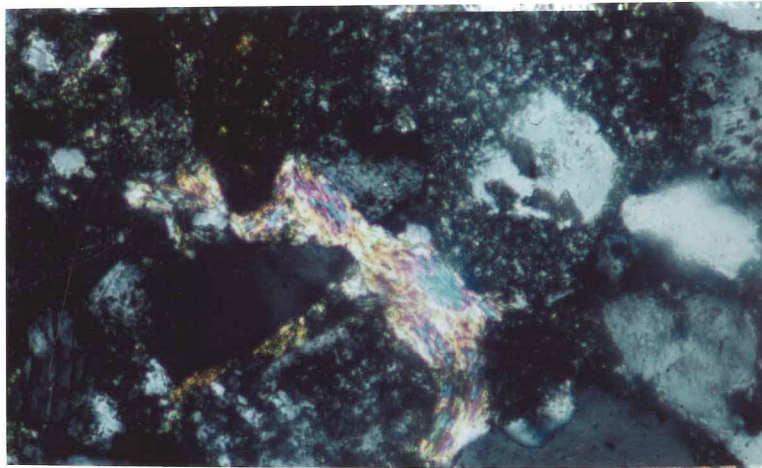
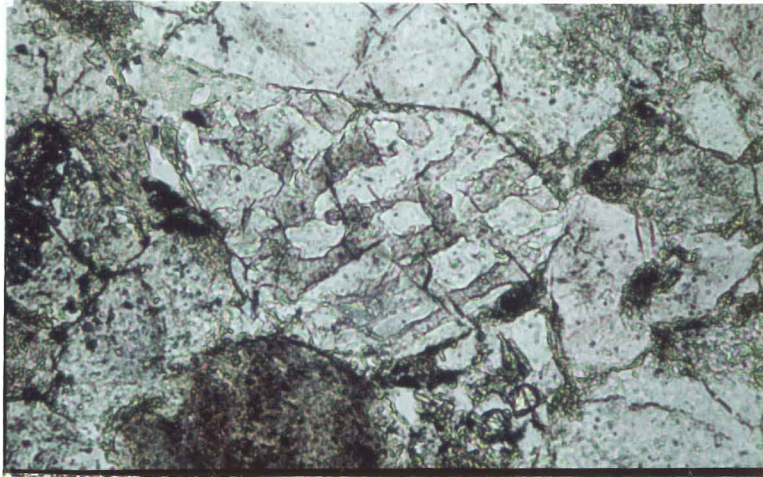
Both plagioclase and alkali feldspars were commonly well twinned and mildly to well zoned. Clear and unzoned grains were also abundant. A few twinnless grains had undulose extinction. Albite was the most common twin but carlsbad and pericline twins were also observed. Pittman (1970) showed that the presence of feldspar zoning indicates an igneous source; Turner (1951) concluded that twinning was relatively rare in many schists and that those twins which were present were albite or pericline. Thus, the occurrence of



fig 4.3 Alkali feldspar weathering  
preferentially in a perthite grain  
X63

Fig 4.4 Mica squashed by compaction  
X63

Fig 4.5 Trachyte-like volcanic clast  
X50



perthites, myrmekites, zoning, and twinning (albite, pericline, and carlsbad) suggests that a major source was igneous rocks.

Differences in weathering made the mechanical behaviour of feldspar variable. Some grains were competent; weathered grains occasionally appeared ductile. Fracturing at grain contacts was rare. Chemically, feldspar components were quite mobile; complex periods of feldspar corrosion and overgrowths were present in the Lower Middelhurst succession (see Chapter 5).

#### c) Micas

Although percent mica varied between the samples, mica type and morphology are consistent. Chlorite, biotite, and muscovite were the detrital micas. The chlorites were both the Mg and Mg-Fe species (determined by color and length fast-slow) and occurred either as monocrystals or fibrous masses. Biotite and muscovites were commonly large monocrystals but also occurred as polycrystalline clusters of mixed biotite and muscovite or individual (biotite or muscovite) aggregates. The micas were frequently squashed (fig 4.4) and occasionally distinction between mono and polycrystalline grains was difficult.

The large monocrystalline biotite, muscovite, and chlorite grains imply an igneous/hydrothermal source. The polycrystalline clusters of chlorite, muscovite, and biotite may originate either from an igneous/hydrothermal or a metamorphic source.

#### d) Lithic Fragments

Lithic clasts are the second most abundant framework component after feldspar. Although a statistical point count was not satisfactory, visual estimates of the identifiable rock fragments were: 50-60% igneous, 30-40% sedimentary, and 5-10% metamorphic. The proportions of igneous to sedimentary clasts varied from slide to slide.

The igneous rock fragments were both volcanic and plutonic clasts in varying stages of weathering. Volcanic rock fragments were difficult to identify because of diagenetic alteration; feldspar microlites were the best clue for identification. Volcanic clasts apparently originate from silic<sup>e</sup>ious, basic, and alkaline sources. Chert-like grains (fig 5.7) may be dacites or rhyolites; grains which have altered to chlorite and/or zeolite suggest a more basic source. Trachytic clasts are common and appear fresh (fig 4.5). Other feldspar rich volcanic clasts have secondary chlorite in the interstitial areas between the microlites. Myrmekite and graphitic quartz and feldspar were the common plutonic rock fragments; their composition implies an intermediate or silic<sup>e</sup>ious igneous source.

Sedimentary rock fragments consisted of mudstone with secondary sericite, mudstone, clean siltstone, dirty siltstone, red and white chert, and greywacke. The perigenic clasts were softer - as shown by their squashing. Some clasts appear to have been well indurated at the time of deposition, for the grains are rounded and have not been flattened.

Clearly recognizable metamorphic clasts are less common. Most of the metamorphic clasts had faint schistosity and were probably low grade rocks. Quartzite was the most common

metamorphic clast. Similar metamorphic clasts have been described in the Torlesse of Canterbury (Smale 1979, Andrews 1980), suggesting that the Middelhurst succession metamorphic clasts are recycled from the Torlesse.

e) Heavy Minerals

The heavy mineral percentage varied from slide to slide. Epidote, sphene, garnet, green amphibole, brown amphibole, and zircon are the most common minerals. Also, Challis (1966) reported detrital prehnite, pumpellyite, pyroxene, apatite, and magnetite in the Tone Fm. Sphene, garnet, brown amphibole, zircon, pyroxene, magnetite, apatite, and green amphibole indicate a basic and intermediate igneous source; garnet, green amphibole, brown amphibole, epidote, prehnite, and pumpellyite may represent a low to high grade metamorphic source (Pettijohn 1975).

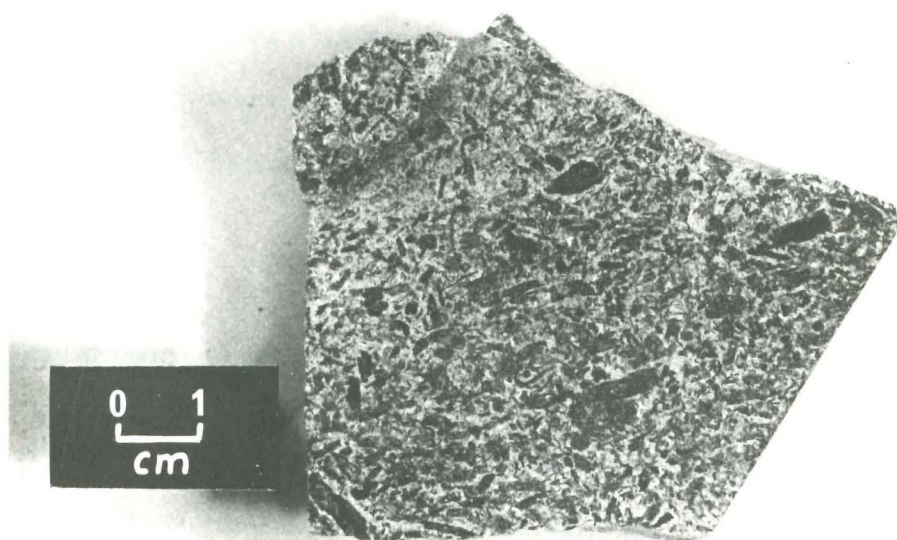
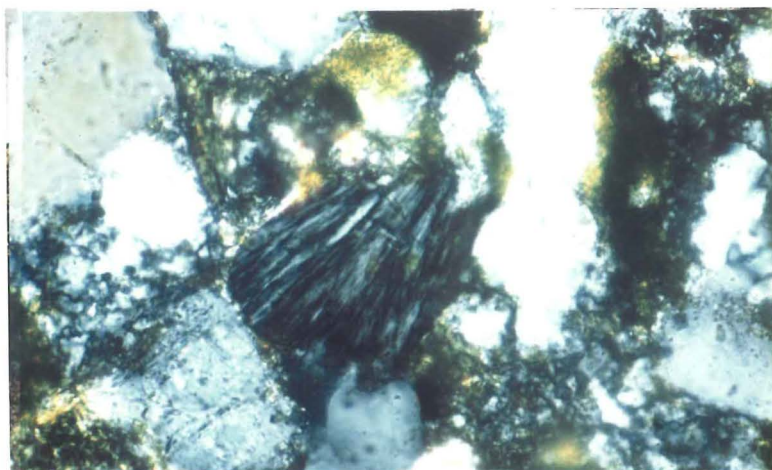
The heavy minerals represent a low percentage of the sandstones, lower than one might expect from arenites rich in igneous clasts. This suggests that either the heavy minerals have been left behind in a coarser sediment size or that weathering has been sufficient to remove most of them.

f) Miscellaneous

Limestone and glauconite grains occur rarely. More commonly, there are detrital zeolites (mordenite and natrolite, fig 4.6) which are too soft to have withstood even moderate abrasion and so must have originated locally. The presence of very fresh trachyte in the sediment also suggests alkaline

Fig 4.6 Detrital Zeolite  
Note the ragged upper grain edge

Fig 4.7 Current Lineation from  
wood rich horizons



volcanism was close by. The closest alkaline igneous centres are only a few miles away in the Inland Kaikoura Range; although these igneous centres (Blue Mountain, Mandamus, and Tapuaenuku) are all dated Ngaterian, these dates reflect cooling and uplift. Thus, it is conceivable that these alkaline centres are the origin for both the trachyte and the zeolites in the Middelhurst succession. The presence of both trachyte and detrital zeolite from the Tone Fm through the Castle Creek Conglomerate suggests the source was active all through the Motuan.

Biogenic clasts are common in all formations. Wood fragments are the most abundant and sometimes give a beautiful current lineation pattern in the bedding plane (fig 4.7).

### 3. Mudstone Composition

True shales are absent in the Middelhurst Succession. Thirty three mudstone samples (Tone Fm: 10, Totara Fm: 7, Gladstone Fm: 6, L. Winterton: 4, U. Winterton: 6) were ground to a fine powder using a ringmill and pressed into discs. The samples were then analysed for major elements by X-ray fluorescence; the results were calculated from a linear regression curve constructed from international and local standards. The curves for all elements had correlation coefficients of at least 0.98. The bulk mineralogy of all the mudstones, as determined by X-ray diffraction, are virtually identical. Most of the standards were intermediate igneous rocks and should have different mass absorption coefficients. However, since the purpose of the analysis is to compare relative abundance of elements and since the



FIGURE 48

## TABLE OF XRF ANALYTICAL RESULTS

## UPPER WINTERTON FM

	PA-1	PA-2	PA-3	PA-4	Ge-19	Ge-20
TiO <sub>2</sub>	0.91	0.92	0.93	0.80	0.90	0.95
MgO	3.2	3.9	3.7	3.5	3.7	3.6
CaO	0.94	1.51	1.51	1.46	1.31	1.22
Na <sub>2</sub> O	1.8	1.5	2.0	2.1	1.6	1.4
K <sub>2</sub> O	3.28	3.24	3.33	2.99	3.25	3.39
P <sub>2</sub> O <sub>5</sub>	0.14	0.12	0.14	0.13	0.13	0.14
SiO <sub>2</sub>	64.87	64.20	63.15	64.01	65.59	61.82

## LOWER WINTERTON FM

	PA-5	Pa-6	Ge-2	Ge-6
TiO <sub>2</sub>	0.86	0.92	0.92	0.92
MgO	3.1	2.9	3.3	3.2
CaO	1.28	1.15	1.44	1.34
Na <sub>2</sub> O	2.1	1.7	2.5	2.2
K <sub>2</sub> O	3.54	3.38	3.40	3.39
P <sub>2</sub> O <sub>5</sub>	0.14	0.13	0.12	0.13
SiO <sub>2</sub>	63.91	63.46	69.63	63.98

## GLADSTONE FM

	Ge-3	Ge-4	Ge-7	Ge-10	Ge-11	Ge-12
TiO <sub>2</sub>	0.79	0.80	0.92	0.71	0.75	0.82
NgO	3.0	3.3	3.1	2.8	3.2	3.2
CaO	1.59	1.76	1.51	1.49	1.86	1.70
Na <sub>2</sub> O	2.3	2.6	2.5	2.1	2.0	2.2
K <sub>2</sub> O	3.48	3.49	3.81	3.11	3.24	3.53
P <sub>2</sub> O <sub>5</sub>	0.14	0.13	0.12	0.12	0.24	0.11
SiO <sub>2</sub>	66.64	64.74	61.26	67.46	65.22	64.04

## TOTARA FM

	Ge-5	Ge-8	Ge-9	Ge-13	To-2	To-3	To-4
TiO <sub>2</sub>	0.77	0.97	0.75	0.72	0.80	0.88	0.86
MgO	3.1	3.7	2.8	2.8	3.8	3.6	3.3
CaO	1.62	1.96	1.70	1.57	1.63	2.18	2.47
Na <sub>2</sub> O	2.2	2.4	1.5	2.6	2.8	2.6	2.9
K <sub>2</sub> O	3.64	3.47	3.27	3.13	3.28	3.05	2.87
P <sub>2</sub> O <sub>5</sub>	0.14	0.18	0.12	0.12	0.13	0.17	0.21
SiO <sub>2</sub>	64.81	60.31	65.43	64.62	63.99	58.30	61.15

## TONE FM

	Ge-1	Ge-24	Ge-23	Ge-22	Ge-21	Ge-18	Ge-16
TiO <sub>2</sub>	0.95	0.96	0.70	0.95	0.72	0.96	0.94
MgO	3.7	3.5	3.0	3.7	3.0	3.8	3.6
CaO	2.49	2.07	2.25	2.37	2.38	2.30	2.14
Na <sub>2</sub> O	2.3	2.2	2.4	1.9	2.4	1.9	2.2
K <sub>2</sub> O	3.14	3.21	2.51	3.25	2.51	2.99	3.06
P <sub>2</sub> O <sub>5</sub>	0.15	0.18	0.16	0.16	0.17	0.18	0.17
SiO <sub>2</sub>	61.72	60.75	63.88	60.91	62.12	60.29	61.44

	Ge-15	Ge-14
	0.90	0.92
	3.4	4.1
	-	2.38
	2.1	2.2
	2.81	2.60
	0.20	0.17
	61.21	61.19

samples had identical mineralogy, the effect of mass absorption should be the same for all the samples and the relative values should be useful. The analytical results are listed on figure 4.8.

Figure 4.9 compares the relative amounts of silica ( $\text{SiO}_2$ ), alkali elements ( $\text{Na}_2\text{O}+\text{K}_2\text{O}$ ), and alkali earth elements ( $\text{MgO}+\text{CaO}$ ). The samples yield remarkably similar results; this supports the results of the point counting (i.e. that the rocks in all the formations are very similar). It is especially important that the rocks show no significant quartz enrichment with time. If the formations above the Tone Fm were entirely cannibalized Torlesse, one might expect a quartz enrichment trend because quartz is chemically and mechanically more competent than feldspar.

Since feldspar is the most abundant mineral in the rocks, the three solid solution components outside the  $(\text{Si},\text{Al})\text{O}_4$  tetrahedrals (i.e. Ca, Na, K) are compared in figure 4.10. A subtle trend from relatively Ca rich Tone Fm rocks to relatively K rich Upper Winterton rocks is evident. The figure also shows that the Totara Fm, mapped previously as Torlesse, is more alkaline than the Tone Fm. The Totara and Gladstone also appear to be more sodic than the Lower and Upper Winterton Fms.

Igneous lithic clasts and heavy minerals are also important components; to evaluate them,  $\text{MgO}$ ,  $\text{TiO}_2$ , and  $\text{P}_2\text{O}_5$  are compared because these elements have less chance of being in feldspar or sedimentary rock clasts (fig 4.11). Although the samples are very similar, the Gladstone, Lower Winterton, and Upper Winterton Fms are slightly richer in  $\text{TiO}_2$  and the Tone and Totara Fms are mildly enriched in  $\text{P}_2\text{O}_5$ .

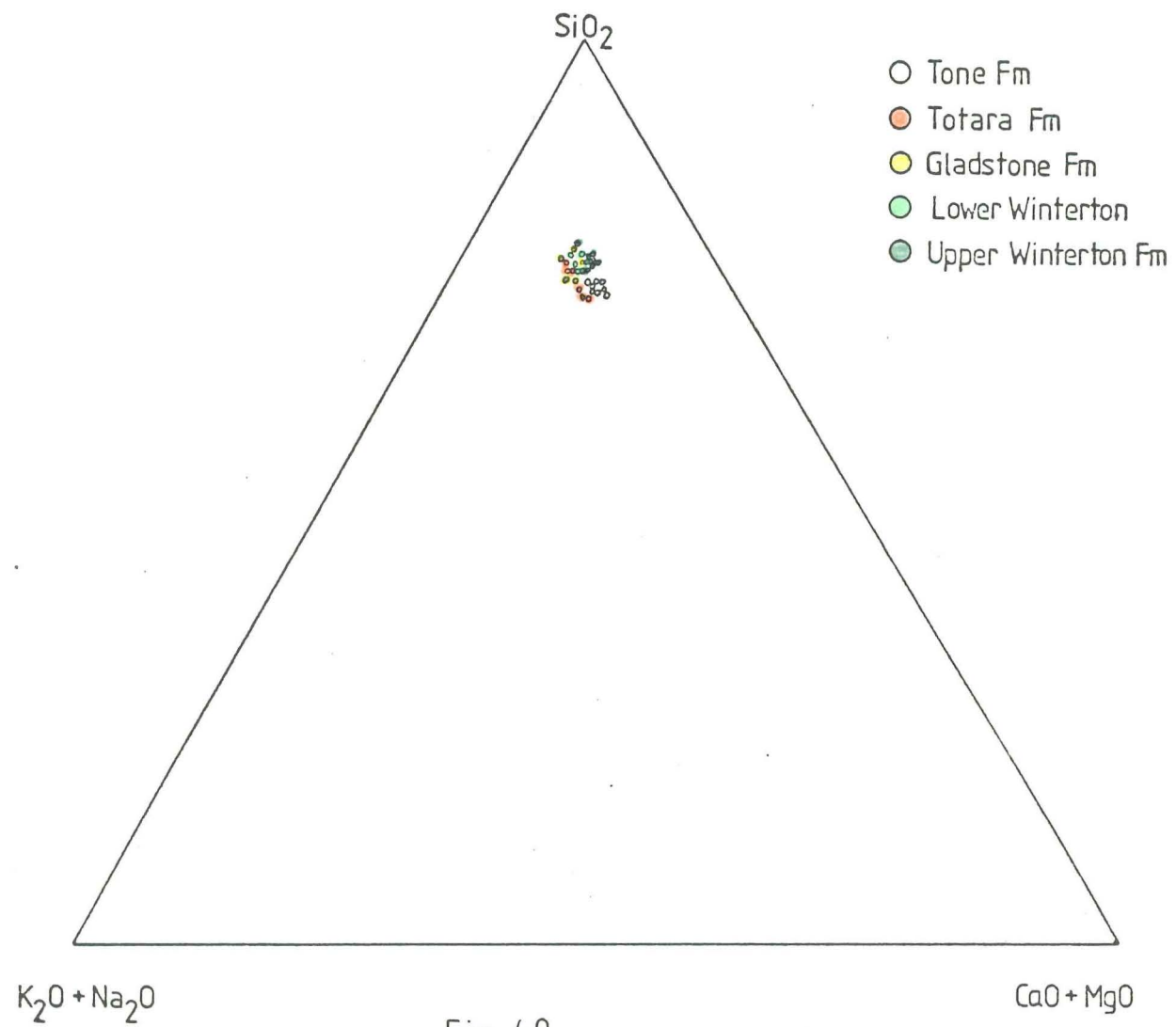


Fig 4.9

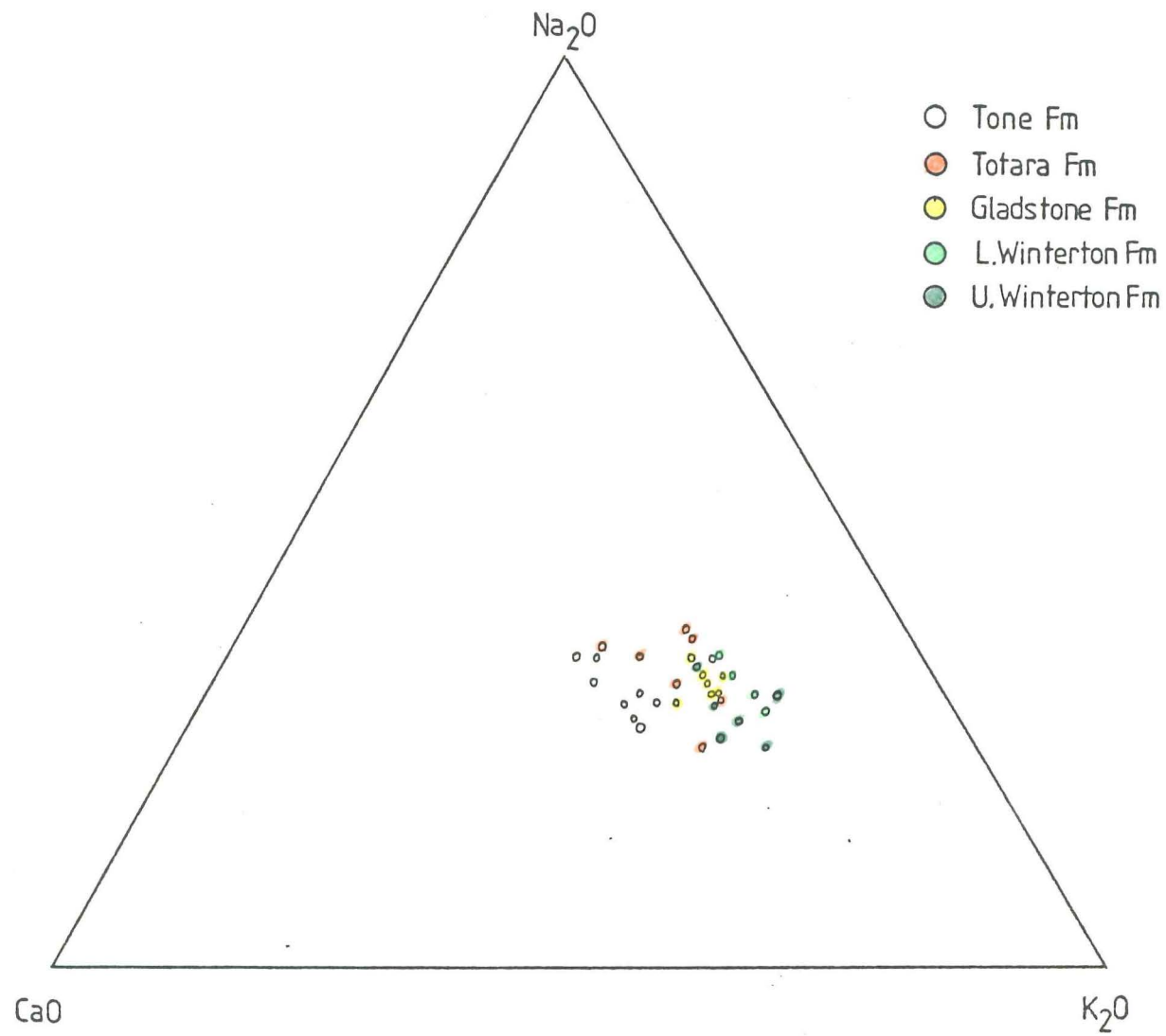


Fig 4.10

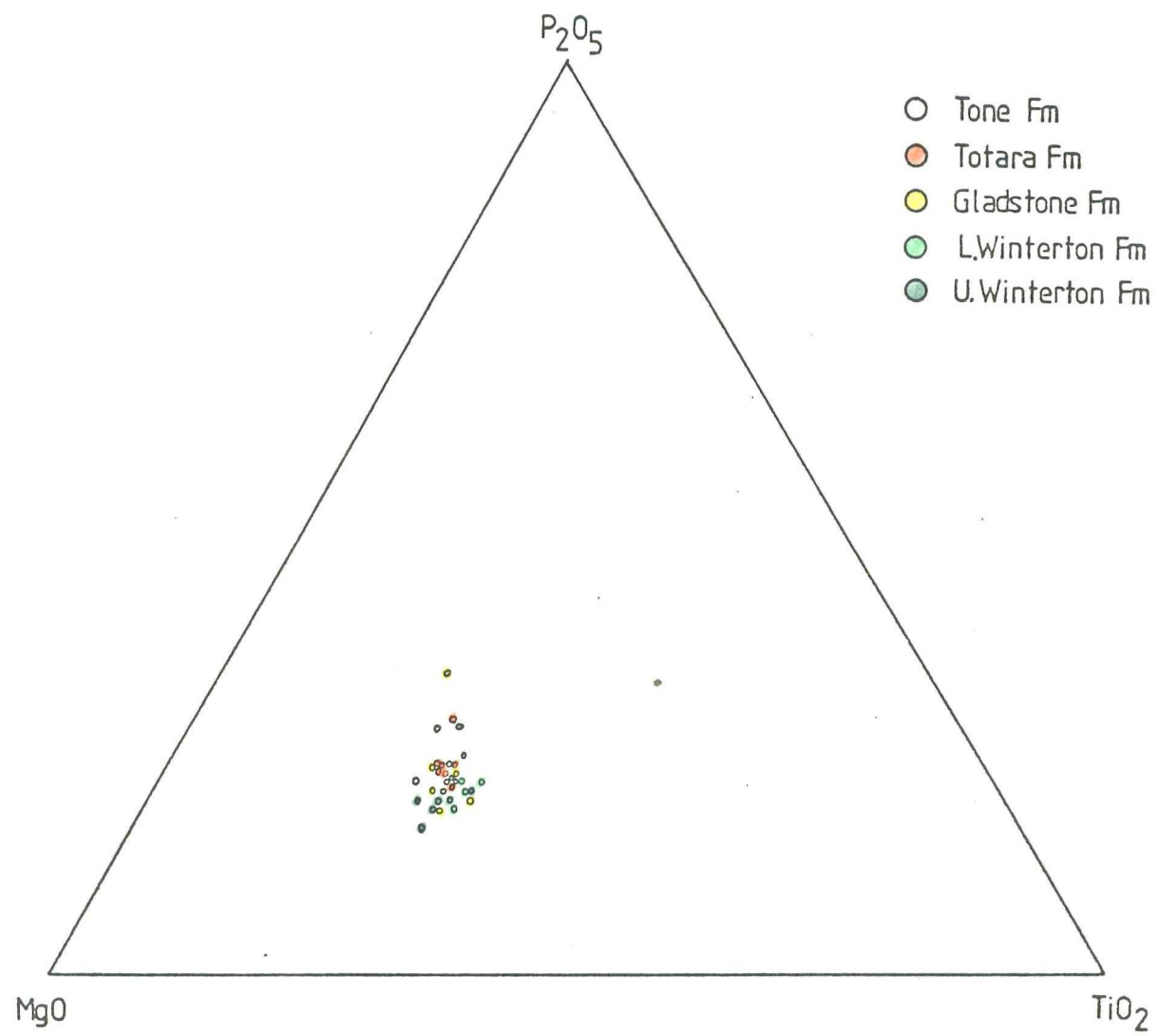


Fig 4.11

Although the formations give very similar results, there are some subtle trends and differences which may reflect the source rocks or the intensity of weathering on the source rocks.

One interpretation of the data is that the change from calcium to potassium rich rocks (fig 4.10) reflects progressive magmatic differentiation in a volcanic source. In figure 4.11, however, the younger rocks appear more "basic" (having relatively more  $MgO$  and  $TiO_2$ ) than the older rocks - the reverse trend of fig 4.10. Since sediments are subject to moderation by chemical and physical weathering and since the heavy minerals and igneous clasts are more susceptible to these processes, any trend on fig 4.11 may be largely fortuitous. The hypothesis relating sediment composition to differentiation in an igneous source area is also dubious because differentiation should produce a quartz enrichment trend; an increase in  $SiO_2$  is not readily observable either from the element analysis or point counts.

Another explanation is that the chemical trends reflect weathering in the source areas. According to Steidtmann (1908), Leith and Mead (1915), Goldrich (1938) and Kennedy (1951), calcium, sodium, and magnesium are the elements most easily lost from a source rock (by solution), potassium and silica are at first enriched, and titanium and phosphorus may be depleted or enriched (more commonly enriched). Thus, figs 4.10 and 4.11 may reflect either increasing weathering intensity in the major source area or a shift in the percentage of detritus from several source areas (each area having different weathering intensities).

As shown from the review of lithic clasts, the provenance

for the Middelhurst succession is a complicated mixture of igneous and sedimentary sources; the chemical trends in the muds may thus reflect both changing source rocks and chemical weathering effects.

#### 4. Conglomerate Composition

Conglomerates were not systematically point counted; however by inspection, sedimentary clasts make up at least 70% of the rock (fig 4.12). This contrasts the sandstone compositions, where sedimentary lithic clasts are subordinate to igneous clasts.

Clast types found in the Gladstone Fm, Lower Winterton Fm, Upper Winterton Fm, and Castle Creek Conglomerate are listed below. No conglomerates were found in the Tone or Totara Fms. The conglomerate compositions were generally similar for all four formations; however, the Gladstone Fm conglomerates contained significantly more vein quartz clasts than the overlying units and the Castle Creek Conglomerate contained the highest percentage of the well rounded and polished pebbles.

#### Conglomerate Clast Types

##### Boulder Size

I      Angular

1. well indurated, structureless, Torlesse-like, sandstone

##### Gravel to Cobble Size

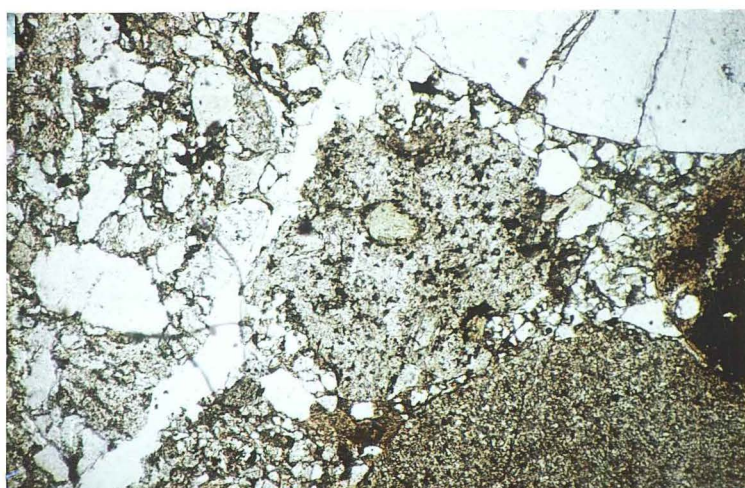
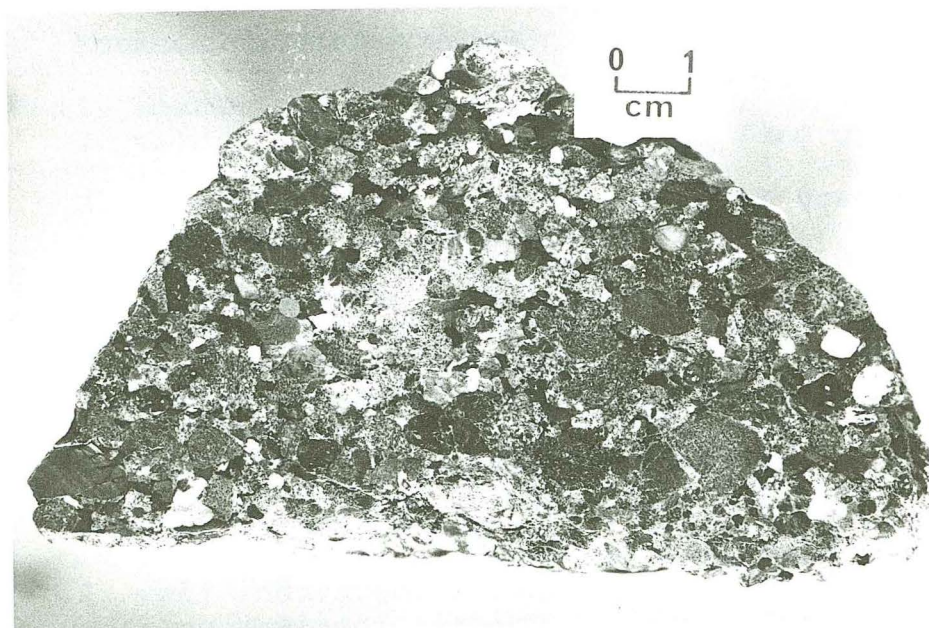
I      Well rounded and polished

1. silicified mudstone
2. chert (red or white)
3. silicified volcanics
4. quartzite



Fig 4.12 Pebbly Conglomerate  
(Gladstone Fm), Note the dominance  
of sedimentary clasts

Fig 4.13 Altered basic volcanic  
clast; ferromagnesian granule has  
weathered to chlorite; also note  
feldspar microlite at the top left.  
X10



## II Rounded to well rounded

1. basalt
2. mildly indurated, fine to very fine grained, laminated, lithic sandstone.
3. well indurated, fine to very fine grained, laminated, lithic sandstone.
4. well indurated, very fine to coarse grained, sandstone (Torlesse-like)
5. well indurated, muddy pebbly conglomerate.
6. well indurated mudstone.
7. mildly indurated mudstone (subsequently flattened).
8. vein quartz (in Gladstone Fm only).

## III Angular to Subangular

1. well indurated, structureless, fine to very fine grained, lithic sandstone (Torlesse-like).
2. mildly indurated, carbonaceous, very fine grained sandstone (coal measures).
3. mud rip up clasts.
4. rhyolite and pumice (in Upper Winterton and Castle Creek Conglomerate only).
5. moderately indurated, fine to very fine grained, laminated sandstone.

The only boulder sized clasts were Torlesse-like and are probably of local origin. The well rounded and polished clasts are chemically and mechanically very durable; similar clasts have been described in Torlesse conglomerates in Canterbury (Smale 1979, Andrews 1980) and it is possible that the Middelhurst succession clasts have been recycled from the Torlesse. The presence of recycled Torlesse conglomerate clasts without any of the original matrix (Torlesse conglomerates are presently well indurated) suggests:

- a) that the clasts have been subjected to rigorous erosion,
- b) that the source is not the Torlesse, or
- c) that Torlesse conglomerates supplying the clasts were not well indurated during the Albian.

In any case, since these Torlesse clasts are still cobble sized, a steep gradient between the source and site of deposition is suggested.

The rounded sedimentary clasts are composed of Torlesse-like rocks, and indurated to moderately indurated rocks with preserved internal stratification. This assemblage suggests that the basement (Torlesse) and overlying Cretaceous rocks were contributing sediment into the Mt. Lookout area. The cobble sized, moderately indurated sandstone clasts could not have survived a long transport and suggest local cannibalization of sediment. Vein quartz was abundant only in the Gladstone Fm; its significance is unknown. Basalt pebbles and cobbles occurred only occasionally; basalt granules were observed under the microscope (fig 4.13) and contained groundmass opaques, plagioclase microlites, and altered olivine granules. The presence of basalt clasts indicates either that weathering was of low intensity or of short duration. The basalt clasts may be primary or Torlesse derived.

The angular clasts also supports the evidence for local erosion. Similar clasts of Torlesse-like and less deformed and indurated sandstones appear as in the rounded clasts. The presence of possible coal measure material suggests significant erosion of a marginal marine or terrestrial area. Most of the less indurated clasts appear to be marine rocks, suggesting that submarine erosion is the dominant source of conglomerate detritus. The presence of rhyolite clasts in the Upper Winterton Fm and Castle Creek Conglomerate and pumice laminae in the Upper Winterton Fm suggests that acid volcanism is contemporaneous with the uppermost Middelhurst succession. None of the rhyolite clasts are larger than pebble size and they do not appear rounded because they are generally flattened by compaction; the original clasts may have been rounded.

In summary, the greatest percentage of conglomerate clasts are of sedimentary origin and appear to be locally derived bedrock and overlying marine deposits. There are also well rounded and polished quartzose clasts which are more likely derived from the Canterbury Suite. Surprisingly, there was no great abundance of trachyte or basalt clasts, for the sandstone compositions suggested a nearby alkaline source. Rhyolitic clasts appeared in the Upper Middelhurst Succession, suggesting contemporaneous acid volcanism; the source may be the Mt. Somers volcanics in Canterbury. No plutonic clasts were found, but the vein quartz may indicate an igneous/hydrothermal source.

#### STRATIGRAPHIC SIGNIFICANCE OF SEDIMENT COMPOSITIONS

The sandstone and mudstone compositions for the Tone Fm, Totara Fm, Gladstone Fm, Lower Winterton Fm, Upper Winterton Fm, and Castle Creek Conglomerate are essentially identical. Given the unusual feldspathic nature of the rocks and the similarity in lithic sandstone clasts between all formations, it is almost inconceivable that rocks considered to be Torlesse (Tone Fm, Totara Fm) were fed by a different drainage system than the overlying units. Therefore, there is no evidence, based on sediment composition, of any major tectonic break below the Lookout Fm.

#### PROVENANCE

##### 1. Source Areas

The morphology, composition, and type of clast or grain indicates at least five source areas are contributing sediment

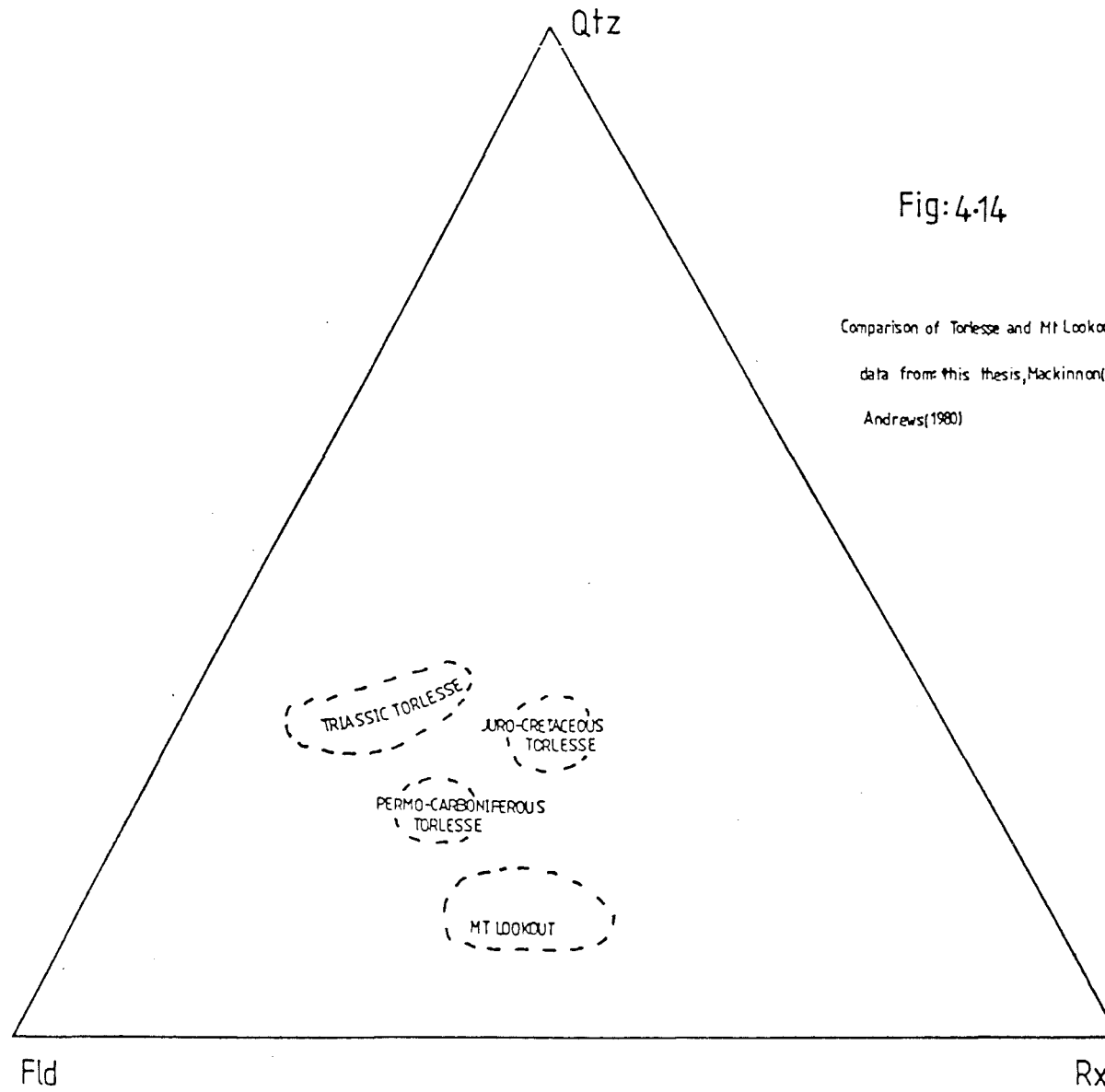


Fig: 4.14

Comparison of Torlesse and Mt Lookout sandstones  
data from this thesis, Mackinnon (1980) and  
Andrews (1980)

to the Middelhurst succession.

The intermediate composition of fresh, zoned feldspar grains, the presence of myrmekites, and the heavy mineral assemblage (sphene, garnet, apatite, biotite, muscovite, green amphibole, and zircon) suggest a plutonic source of intermediate composition. The Torlesse is also a source and itself is derived from a plutonic source (Mackinnon 1980), so some of the plutonic material may be recycled. However, the high percentage of feldspar (comparable with the Rakaia Torlesse, fig 4.14) and the fresh appearance of some of the feldspar grains argues that the plutonic source is primary. The Separation Point Granites are of a similar age to the Middelhurst succession but the K-Ar age represents cooling and not erosion, so the Separation Point Granites may be too young. The Tuhua granites are a definite possibility. However if one <sup>also</sup> accepts the Lower Cretaceous reconstructions of New Zealand, Tuhua granites should be some 400 km away - and across the Rangitata orogen; transport to Marlborough through the orogen is perhaps less probable.

The appearance of rhyolitic clasts in the Upper Middelhurst succession and the presence of siliceous volcanic grains indicate a source of intermediate to acidic volcanism. A possible source is the Mt. Somers volcanics in Canterbury, again some 200 km away. Another possibility is the volcanic pile which presumably overlay the Separation Point Granites. Either way, it is difficult to reconcile a source without a considerable transport distance across the Rangitata orogen.

The presence of trachyte and basalt grains, basalt clasts, the heavy minerals magnetite and pyroxene, and

detrital zeolite indicate alkaline-basic volcanism in close proximity to Mt. Lookout. The only possible source which could meet these requirements is the Inland Kaikoura igneous belt, which presumably also contained a volcanic pile. The Inland Kaikoura igneous centres at Blue Mountain and Tapuaenuku and their extrusive equivalents in the Awatere (Lookout Fm) and Clarence (Gridiron Fm) Rivers are Ngaterian in age. However, the volcanic equivalents to the intrusive centres may have begun forming in the Motuan. If this is so, the S.W.-N.E. trend of the intrusive centres may represent a physiographic submarine high during the Motuan.

The presence of recycled well rounded and polished clasts, the very weathered feldspar, the rounded quartz, and rounded indurated sedimentary clasts indicate that the Torlesse terrane is also an important source. Some of the clasts may be of more local (Pahau sub terrane) origin, while others appear to have been derived from Rakaia sub terrane rocks. The presence of low grade metamorphic clasts and detrital prehnite and pumpellyite possibly indicate that metamorphosed (Rakaia sub terrane) Torlesse rocks were also being eroded.

The final major source is cannibalized sediment, presumably from moderately lithified rocks of roughly the same age as the Middelhurst succession. The bulk of this detritus appears to be marine rocks, although there may be some terrestrial recycled sediment as well.

## 2. Tectonic Significance Of The Provenance

The provenance indicates important aspects about tectonic conditions in Marlborough and has implications for



New Zealand Lower Cretaceous paleogeography.

The presence of recycled, cannibalized, conglomerate and sandstone in the Middelhurst succession implies that tectonism was active in Marlborough during deposition of the Middelhurst succession. The presence of a basic-alkaline volcanic source in close proximity to Mt. Lookout indicates that volcanism accompanied tectonism in Marlborough. The existence of basement derived detritus from the Pahau and Rakaia sub terranes and the presence of Rakaia low grade metamorphic grains may indicate that the continental foreland was high.

The intermediate plutonic and the rhyolitic source areas are problems which need further work. At the moment two possibilities exist.

One explanation, mentioned briefly beforehand, is that the plutonic derived sediments are derived from the Separation Point or Tuhua granites. This explanation requires that drainage cut across the Murihiku, Maitai, Dun Mountain, Caples, Haast Schist, and Torlesse terranes. If this were so, one would expect to find detritus from these other terranes in the Middelhurst succession. Since the Maitai, Dun Mountain, and Caples terranes are composed predominantly of unstable lithics, these terranes may not be detectable; the Haast Schist, however, should be. The morphology of the mica and the heavy mineral assemblage of the Middelhurst succession suggests a possible metamorphic source. I found schist-like fragments in the sandstones (as did Challis, 1966) but the resolution of schist grains 1 mm or smaller is confused by weathering and by sericitization of mudstone fragments. Reay (1980) also hypothesised

a low to high rank metamorphic source for the Split Rock Fm based on heavy minerals. Since there is also a metamorphic source to the Torlesse terrane (Andrews et al 1976) the heavy minerals in the Awatere and Clarence Valleys may be in part or entirely recycled. Thus, because the presence or absence of the Haast Schist is uncertain in Clarence age sediments in Marlborough the source for the plutonic grains is unresolved.

An alternative explanation for the plutonic source is to derive the sediment from an unknown source and transport it to Marlborough by longshore drift. Because there are no known granites near the Cretaceous continental margin, the source would have to be Marie Byrd Land (at least 1000 km away) or Australia (another 1000 km away). Although such long transport distances are not prohibitive, one might expect the mechanical abrasion to enrich the sediments in quartz, when in fact the source appears to be mainly feldspathic.

The rhyolite clasts may originate from either Mt. Somers or the volcanic pile which once lay over the Separation Point Granites. Similar rhyolite clasts occur in Motuan rocks in the Clarence valley (M. Reay 1980); more work on the distribution of rhyolite clasts may suggest which of these two sources is more likely.

In summary, the provenance suggests active tectonism and volcanism in Marlborough during the deposition of the Middelhurst succession. This implies that the Middelhurst succession is a synorogenic and not a post orogenic deposit. The presence of fresh feldspar and the similarity in percent feldspar relative to Torlesse (Rakaia) rocks suggests a significant, primary, feldspar rich source. This felsic

source may indicate a major drainage system across the Rangitata Orogen.

### 3. Paleoclimate

The mineralogy of the sandstones suggests that for most of the five source areas, weathering was incomplete.

The Middelhurst succession sandstones are deficient in heavy minerals which one would expect from a nearby basic-alkaline source. Some of the basalt clasts appear to have been weathered before deposition and basalt conglomerate sized clasts are not as abundant as one might expect. Yet, detrital zeolites are present, so the detritus could not have travelled very far. The basic-alkaline source was probably a submarine volcano and chemical weathering by sea water (as reflected by the detrital zeolites) is probably responsible both for the small grain size and the lack of heavy minerals.

The terrestrial sources (i.e. the plutonic, rhyolitic, and Rakaia sub terrane rocks) suggest mild chemical weathering. The existence of plentiful recycled and primary feldspar argues against effective chemical weathering. The bulk chemical compositions of the mudrocks and the general lack of quartz also indicates modest chemical weathering. In fig 4.15 the bulk chemistry of the Middelhurst succession mudstones is similar to the chemistry of possible source plutonic rocks. Goldrich (1938) and Kennedy (1951) have shown that weathering of intermediate igneous and metamorphic rocks by solution at first removes  $\text{Na}_2\text{O}$ ,  $\text{CaO}$ , and  $\text{MgO}$ ; then  $\text{K}_2\text{O}$ ,  $\text{SiO}_2$ , and  $\text{TiO}_2$ ; finally  $\text{FeO}$  and  $\text{Al}_2\text{O}_3$ . The increase of  $\text{K}_2\text{O}$ ,  $\text{TiO}_2$ ,  $\text{SiO}_2$  and perhaps even  $\text{MgO}$  in

the Middelhurst succession relative to the potential source rocks indicates that weathering has only progressed to Goldrich's and Kennedy's first stage. Considering that much of the Middelhurst succession is second cycle material derived from igneous rocks, the strong resemblance of the Middelhurst succession to original intermediate igneous source is remarkable and implies relatively mild weathering. The scarcity of fine to very fine grained quartz also argues against effective chemical weathering. Quartz is easier to reduce to fine grain size in humid conditions because  $\text{SiO}_2$  is more susceptible to solution (Crook 1967). Feldspar is less stable in humid conditions, so one would expect even the fine grained fraction to be enriched in quartz if chemical weathering was influential.

In summary, despite the textural maturity of the sediments, the chemical immaturity of the detrital minerals suggests that either the intensity of chemical weathering was low or that the duration of chemical weathering was short. Which of these possibilities is more likely?

Work by Stevens (in Stevens and Speden 1978) suggests that the Cretaceous climate of New Zealand was temperate. Tree and fern fossils are common in the Lower Cretaceous and conifers appear to be the dominant tree type (this does not imply a cool climate because angiosperms were not abundant during the Cretaceous, Levin 1978). The presence of fossil tree rings does, however, indicate that the climate was seasonal. Marine invertebrates during the Cretaceous apparently change from a more cosmopolitan "tethyan" fauna to a more provincial "austral" fauna, which Stevens (in Stevens and Speden 1978) suggests might reflect

a modestly cooling climate. Paleomagnetic reconstructions during the Albian by Oliver et al (1979) place New Zealand only  $10^{\circ}$  from the south pole. At such a latitude the winter months must have been cold and dry for trees to survive attacks by fungi (J. Lovis pers comm). Moisture is more important than temperature for chemical weathering (Pettijohn 1975, Basu 1976, Garner 1959); in the Gridiron Fm (Clarence Valley) the macroflora includes Bennettites which suggests a warm humid climate (J. Lovis pers comm). However the floral assemblage in the Gridiron Fm appears to be a swamp-lakeside deposit (Reay 1980) and so may only reflect local conditions. The large volume of plant matter in Clarence aged rocks of the Awatere and Clarence Valleys, at Kyeburn (Bishop and Laird 1976), and in the Great South Basin (Kawau 1-A, HoïHo 1-C) suggests, however, that forestation was extensive.

Thus, there appears to be a major contradiction: the sediments suggest only mild chemical weathering but plant and marine fossils indicate a temperate, at least seasonally humid climate. This dilemma may be explained by high erosion rates coupled with graduated climatic zones.

The paleoclimate's seasonality and New Zealand's close proximity to the south pole suggests that climate should change with elevation. Thus, if most of New Zealand was a highland (fig 4.16) the bulk of the sediment could be derived from a cold climate where moisture is locked up in the form of snow or frost. Spring melting of the snow would then cause erosion and transportation of the detritus down through the temperate lowlands and into the sea. Present day situations similar to this can be found in S.E. and

FIGURE 4.15

COMPARISON OF MIDDELHURST SUCCESSION COMPOSITIONS WITH  
POSSIBLE SOURCE ROCKS

	Continental Andesites	Island Arc Andesites	Diorite	Triassic Torlesse	Middelhurst Succession
SiO <sub>2</sub>	58.65	58.68	56.77	60.61	63.40
TiO <sub>2</sub>	0.79	0.81	0.66	0.67	0.87
MgO	3.28	3.14	2.80	2.74	3.30
CaO	6.26	7.13	5.38	0.91	1.71
Na <sub>2</sub> O	3.82	3.24	3.37	2.71	2.17
K <sub>2</sub> O	1.99	1.27	2.10	3.41	3.25
P <sub>2</sub> O <sub>5</sub>	0.18	0.17	0.26	-	0.14
	Syenite	Quartz Diorite	Granite		
	60.19	61.59	70.18		
	0.67	0.66	0.39		
	2.49	2.80	0.88		
	4.30	5.38	1.99		
	3.98	3.37	3.48		
	4.49	2.10	4.11		
	0.28	0.26	0.19		

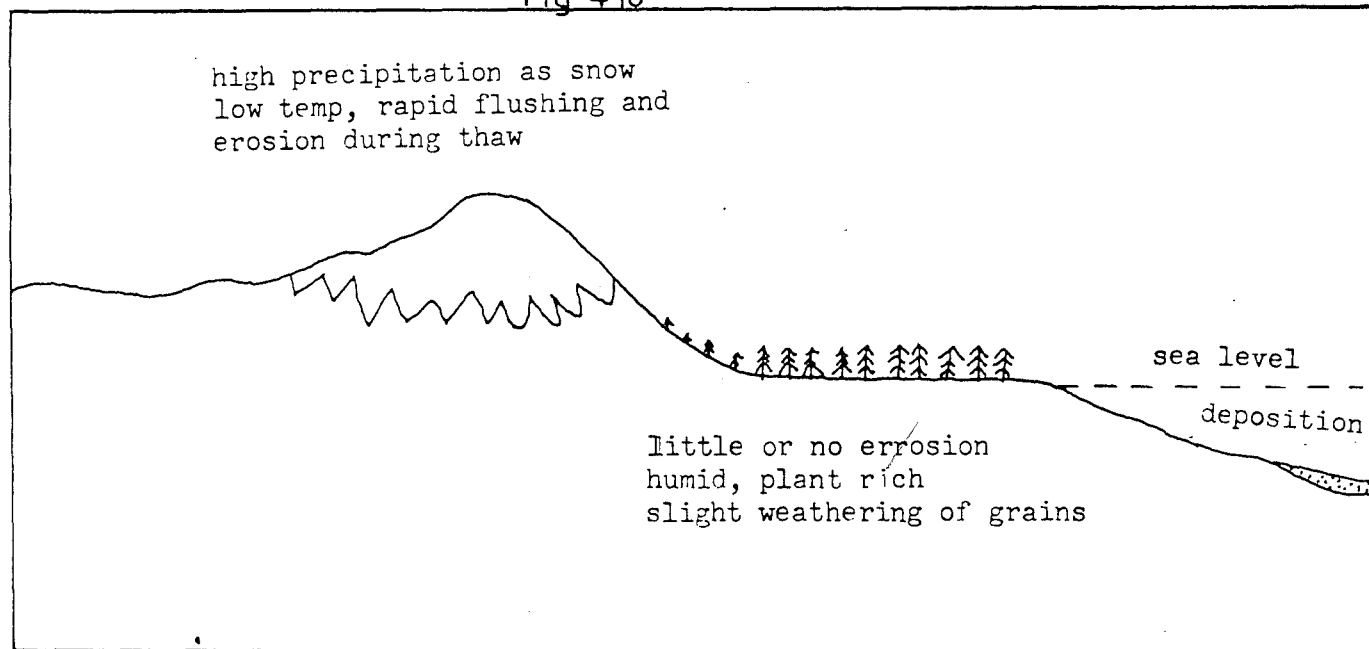
Data from Daly and Larsen (1942)  
Reed (1957)

A. Macbirny Pers Comm  
T. MacKinnon (1980)

MINERAL COMPOSITIONS

	GRANITE	QTZ DIORITE	DIORITE	SYENITE	MIDDELHURST SUCCESSION AVR.	TRIASSIC TORLESSE AVR.
QTZ	25	20	2	-	10	26
K-Fld	40	6	3	72	9.6	9
Plag	26	56	64	12	36	34
BiO	5	4	5	2	1	4
Amph	1	8	12	7	<1	-
OPX		1	3		-	
CPX		3	8	4	-	
Mag/ILL	3	2	2	2	<1	

Fig 4.16



south central Alaska. The suggestion that much of New Zealand existed as highlands is not inconsistent with the provenance of the Middelhurst succession. Also, K-Ar uplift and cooling dates suggest continuous uplift of the Rangitata Orogen from Lower Jurassic through Lower Cretaceous time (Adams, 1979); in fig 4.17, the swarm of granite cooling ages during the Albian suggests intense uplift and an avalanche of sediment must have resulted.

There is one problem with this explanation, however; if mechanical weathering was dominant one might expect more coarse grained material, yet fine to very fine grained sandstones dominate the Middelhurst succession.

#### 4. Abrasion History

The very fine to fine grained sandstones were derived from sources within continental New Zealand and transported to Marlborough by rivers. The sand is inferred to have moved quickly offshore because any extensive coastal reworking of the sediment would destroy the lithic components (Davis and Ethridge 1975). Moving basinward, the very fine to fine grained sand became periodically mixed with locally derived, boulder to silt sized material, during periods of marine erosion. The large volume of well sorted, very fine to fine grained sandstone suggests that the updip river system was the major source of sand sized sediment coming into the Mt. Lookout area.

The textural maturity and chemical immaturity of the sandstones may be caused by a number of processes. If the identification of the source areas is correct, one of the



biggest problems is a long rapid fluvial transport without breaking down feldspar or lithic fragments (Davis and Ethridge 1975, Mack 1978). One explanation for the abundance of fine to very fine grained sandstones is a size segregation process located between the sources and the site of deposition. Ruxton (1970) describes such a region in Papua, N.G. where the coarse sediments are trapped in a region where the topography shows a marked break between steep mountains and a flat floodplain. By the time sediment reaches the beach environment, fine grained sands are the dominant size, the sands are well sorted, and quartz is still only 5% of the sediment. The Ruxton model is attractive because it agrees with the paleoclimatic model discussed earlier (fig 4.15). Another simpler explanation is that the source areas supply mainly fine grained feldspathic and lithic sediment. This situation is likely because the Torlesse terrane is dominantly very fine to medium grained sand (Andrews et al 1976) and the plutonic source may be a fine grained intrusive.

In summary, the textural maturity and lack of quartz is a problem. However, given the modest percentage of quartz in the fine and very fine grained sandstones throughout the Torlesse terrane (Mackinnon 1980), there are apparently processes which can account for the sediment character.

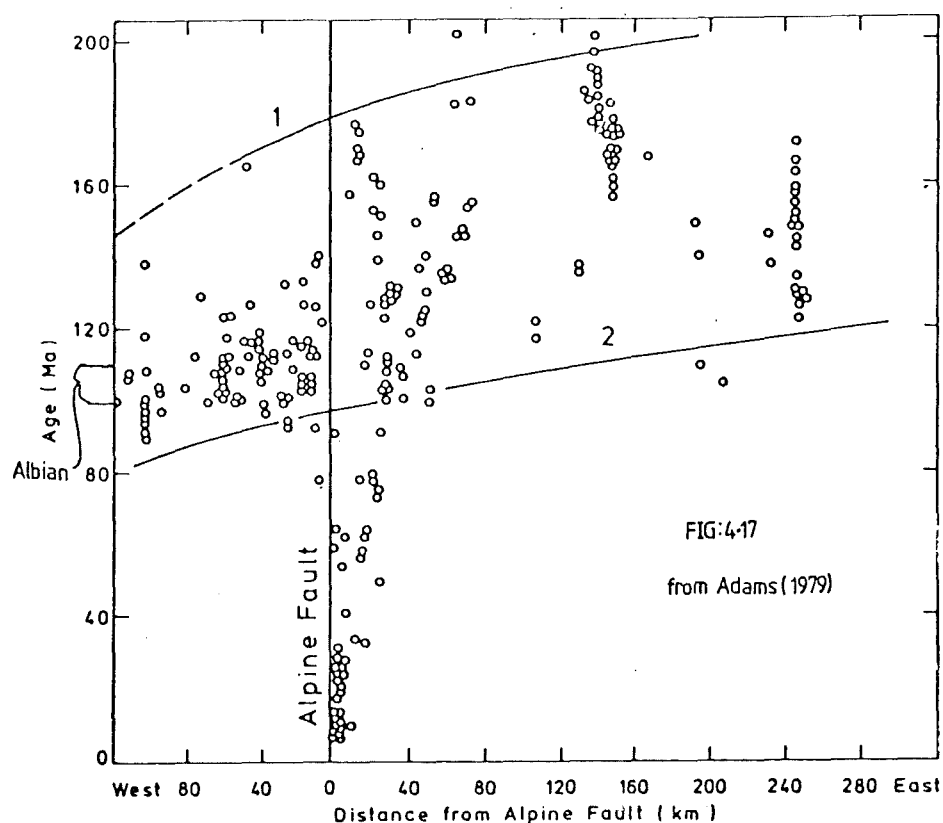


Fig. 2—Mineral ages from metamorphic and plutonic areas of the Rangitata orogenic belt shown in relation to the Alpine Fault. Boundary Lines 1 and 2 define time limits of Rangitata uplift. Line 1 provides a minimum age for metamorphism in the Haast Schist and Torlesse terranes. Line 2 provides a younger age limit for post-orogenic uplift in the South Island.

## CHAPTER 5: METAMORPHISM AND DIAGENESIS

## PART 1: METAMORPHISM

INTRODUCTION

Several authors (Gair 1969, Speden . 1978, and Laird 1980) have stated that the regional unconformity separating Torlesse and post Torlesse rocks is marked by a significant change in metamorphic rank across the contact. This means that there must be a missing metamorphic grade or facies between the Torlesse and overlying rocks. A hypothetical example would be amphibolite facies rocks overlain by zeolite facies rocks - the missing layer being the entire green-schist and prehnite facies. Prehnite-pumpellyite facies rocks overlain by zeolite facies rocks, however, do not constitute a significant change in metamorphic rank because these grades are sequential (assuming the rocks were metamorphosed at the same time).

The presence or absence of a metamorphic break is significant when evaluating the stratigraphic-tectonic significance of an unconformity. If there is a metamorphic break, one may conclude that a significant period of erosion must have occurred before the overlying rocks were deposited; if there is no missing metamorphic grade, one cannot presume a deep level of erosion.

The purpose of this section is to describe the metamorphic stratigraphy in the Mt. Lookout outlier and examine the evidence for or against a significant change in metamorphic rank from Torlesse-like rocks to overlying rocks. To accom-

plish this I will: a) summarize mineral stabilities and secondary mineral paragenesis in burial metamorphism, b) describe and interpret the mineral assemblages and metamorphic stratigraphy of the Middelhurst succession, and c) discuss the results.

MINERAL STABILITIES AND SECONDARY MINERAL PARAGENESIS IN  
BURIAL METAMORPHISM FROM EXPERIMENTAL AND GEOLOGIC WORK  
ELSEWHERE

The Middelhurst succession, although severely deformed in part, has no consistent penetrative fabric and so constitutes a burial metamorphic sequence in the sense of Coombs (1961). Previous work on other burial metamorphic successions has suggested that the stability of detrital clays (kaolinite, smectite, illite) and other minerals (feldspar, biotite) reflect various pressure and temperature zones within the sequence; metamorphic zones are also marked by the appearance of new minerals (chlorite, zeolites, prehnite, and pumpellyite). The following discussion is generalized and the reader is reminded that low grade metamorphic reactions are dependent on other complex geochemical conditions besides temperature and pressure and that reactions are often incomplete.

1. Stability of Detrital Components

a) Kaolinite

The stability of kaolinite is thought to be dependent on the geochemistry of the pore fluids at lower temperatures (De Segonac 1970); never-the-less, several authors have

reported a thermal stability limit between 140°C and 210°C (Muffler and White 1969, Boles and Franks 1979) or before prehnite grade metamorphism (Frey 1970). Experimental work on kaolinite stability in the system  $K_2O-Al_2O_3-SiO_2-H_2O$  found that kaolinite breaks down in the presence of sea water above 100°C (De Segonac, 1970). Differences in percent kaolinite may not, however, always be attributable to metamorphism because sedimentary facies may vary significantly in the percentage of detrital kaolinite (Perry and Hower 1969, De Segonac 1970). In summary, the presence of detrital kaolinite suggests that temperatures have not exceeded 200°C for any significant length of time.

#### b) Smectites

Discrete smectites convert gradually to illite with increasing burial metamorphic grade (Perry and Hower 1969, Hower et al 1976); this transformation takes place via an intermediate illite/smectite interlayered series (De Segonac 1970, Hower et al 1976). Work on presently active burial metamorphic sequences suggests that discrete smectites change to interlayered smectite/illite clays between 50°C and 100°C (Muffler and White 1969, Boles and Franks 1979, Hoffman and Hower 1979).

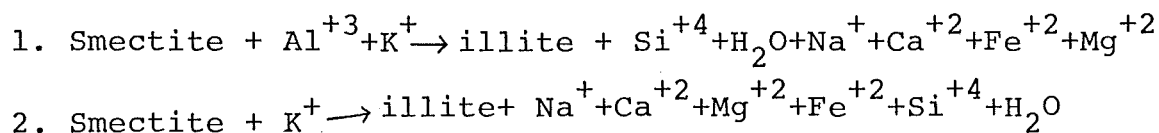
#### c) Illites

Illites are relatively stable minerals in burial metamorphism but still undergo a progressive change; IMd and IM are the most common detrital illite polymorphs and these forms may progressively change to a 2M polymorph during burial metamorphism (De Segonac 1970). This change is

in part a reduction of amorphous or foreign clay layers from the illite structure and is reflected by an increase in crystallinity. This change can be roughly quantified by measuring the crystallinity index (the width of the 001 peak at half height) (De Segonac 1970). However, since the intensity of 001 reflections is dependent on composition, the crystallinity ratio is commonly plotted against the ratio of the 002/001 peaks (at  $5\text{\AA}^{\circ}$  and  $10\text{\AA}^{\circ}$  respectively) (De Segonac 1970, Frey 1970).

#### d) Illite/Smectites

The conversion of smectite to illite involves substitutions both in expandable layers and interlayers; Hower et al (1976) favour reaction #1 and Boles and Franks prefer reaction #2:

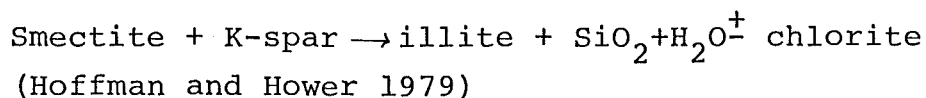


Previous work on burial metamorphic sequences suggests that the transformation of smectite layers to illite is rapid until 80% of the layers are illite (Perry and Hower 1969, De Segonac 1970, Hower et al 1976). The 80% illite clay (in shales) is then stable over a fairly wide temperature range from  $100^{\circ}\text{C}$  to  $200^{\circ}\text{C}$  (Muffer and White 1969, Boles and Franks 1979). Frey (1970) found that (in pelitic rocks) interlayered clays had disappeared before the laumontite-prehnite-quartz assemblage developed.

#### e) K-Feldspars

The breakdown of K-feldspar in both sandstones and shales

with increasing burial metamorphic rank is reported by Hower et al (1976), Boles and Franks (1979), and Hoffman and Hower (1979); this change is thought to be related to the smectite to illite transformation:



However, K-feldspar may be stable in a variety of low grade metamorphic environments (D. Shelley pers.comm.) so that it's use as a monitor of metamorphic grade is uncertain.

#### f) Albitization

Several authors have reported sodium metasomatism in sandstones of burial metamorphic sequences (Coombs 1961, Dickenson et al 1969, Boles and Coombs 1976) beginning at low temperatures (50°C) and suddenly increasing at the beginning of the zeolite facies. Work on the Great Valley Sequence by Dickenson (1969) suggests that albitization may be essentially complete in sandstones buried close to 6 km. and at approximately 120°C. Boles (1977) theorizes that the common association of increased albitization with the onset of zeolite facies metamorphism represents an important source of calcium for the forming of laumontite and heulandite.

## 2. Secondary Minerals

### a) Chlorites

Secondary chlorite content is cited by several authors to increase with burial metamorphic rank (Dickenson et al 1969, Frey 1970, De Segonac 1970). The onset of secondary

chlorite depends on a variety of geochemical conditions and has been reported to begin in sandstones as low as 70°C (Hoffman and Hower 1979) or as high as 140°C (Boles and Franks 1979). In shales the lowest reported onset of secondary chlorite is at about 70°C (Hower et al 1976). The presence of chlorite is not easy to interpret because it may also form diagenetically and is a common detrital mineral.

#### b) Zeolites

Zeolites may be very useful paleothermometers in burial metamorphic sequences. Zeolites may form over a wide variety of conditions from STP to over 200°C at several kilobars pressure (Hay 1977, Coombs 1971). In burial metamorphic sequences the paragenesis of zeolite is influenced by fluid chemistry, rock permeability, and sediment composition (Stewart and Page 1974, Boles 1977). Coombs (1971) has defined the zeolite facies as a mineral assemblage characterized by ca-zeolite + chlorite + quartz in rocks of favourable composition. In sedimentary rocks, the most common assemblage is ca-zeolite + authigenic quartz + albite + adularia + clay. Although certain zeolites, prehnite, and pumpellyite have overlapping temperature stability fields (Hoffman and Hower 1979) zeolite minerals are generally not associated with prehnite and pumpellyite grade metamorphism (Boles 1977). A simplified mineral zone progression (from lowest to highest grade) would be: 1) clinoptilolite + mordenite, 2) analcime + heulandite, and 3) laumontite + albite (see fig 5.1)



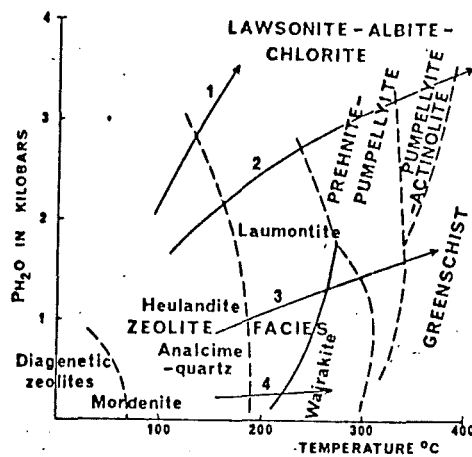


Figure 3. Possible P-T fields for low-grade mineral facies and subfacies, calibrated for the laumontite-wairakite and analcime + quartz-albite reactions (21, 3). Where  $P_{H_2O} < P_{total}$ , boundaries are displaced to the left. Arrows represent facies series as follows, slightly modified from Sekt (35).  
from Coombs (1971)

- (1) High pressure, low temperature
- (2) Intermediate
- (3) Low pressure intermediate
- (4) Lowest pressure

fig 5.1

## MINERAL ASSEMBLAGES AND METAMORPHIC STRATIGRAPHY OF THE MIDDELHURST SUCCESSION

The mineral assemblages at different localities in the Middelhurst Succession are summarized in fig 5.2.

### 1. Winterton River Area

#### a) Mudstones

The clay mineral assemblage (percentages are listed in fig 5.4) in the mudrocks was generally consistent between the formations and the clay assemblage did not vary systematically within a particular formation from locality to locality.

None of the Middelhurst Succession mudstones contain discrete smectite; I am not certain whether this is a depositional or post depositional feature. In modern ocean sediments, smectites average 38% of the clay content and are particularly abundant in cold climates and/or when derived

FIG 5.2  
metamorphic stratigraphy

A

Winterton R.

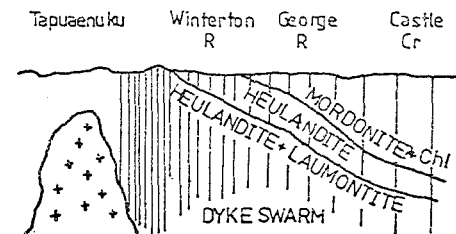
stratigraphic unit	zone	mineral assemblage	
		mud	sand
Upper Winterton Fm	3	Ill+Kao+Ill/Sm+Chl	Zeol (diagenetic)
Lower Winterton Fm	2	Ill+Kao+Chl	Zeol (diagen) + Chl + Olig + Kspar + Ab
Gladstone Fm	1	Ill+Kao+Chl ± Ill/Sm	laumontite + heulandite + Zeol (diagen) + Chl + Olig + Kspar + Ab
Totara Fm			
Tone Fm			

B

Middelhurst Cr—Castle Cr

unit	zone	mineral assemblage	
		sand	mud
Castle Cr Cong.	B	Zeol (diagen) + Olig + Kspar + Ab	Ill+Kao+Ill/Sm+Chl
Upper Winterton			
Tone Fm	A	mordenite + natrolite grps + Chl + Olig + Kspar + Ab	Ill+Kao+Ill/Sm+Chl

diagrammatic sketch of the  
relationship between the  
dyke swarm intensity and  
metamorphic assemblage



from weathered volcanic sources (Blatt et al 1980). Although authors have described the breakdown of smectites in marine environments (Millot 1970), the favourable paleoclimate and provenance of the Middelhurst Succession (see Chapter 4) suggests that detrital smectites should have been present. If there were detrital smectites, the present clay assemblage suggests that most of it has converted to illite.

Only the Upper Winterton Fm. and the Tone Fm. contain interlayered smectites. The Tone Fm. smectites are interlayered with illite and chlorite. Untreated smectites have a 001 peak ranging from  $13.6\text{\AA}^{\circ}$  to  $15\text{\AA}^{\circ}$  depending on the amounts of calcium and sodium. After treatment with glycol-alcohol the clay should swell and the 001 peak should migrate to  $17.6\text{\AA}^{\circ}$  (Carrol, 1970). In figure 5.3 the glycolated 001 smectite peak in both the Tone Fm. and Upper Winterton Fm. is poorly crystalline, suggesting a poorly ordered structure. Unfortunately I have not had time to work out the percent smectite in the illite/smectite clays, but the very existence of smectite interlayers in the Tone Fm. suggests that temperatures never exceeded  $200^{\circ}\text{C}$  for any length of time.

The lack of interlayered smectites in the Totara Fm., Gladstone Fm., and Lower Winterton Fm. (note the absence of swelling in Fig. 5.3) is an anomaly because these units appear to have a metamorphically more mature clay assemblage than the underlying Tone Fm.

Kaolinite is present in all the formations (the 001 peak is at  $7\text{\AA}^{\circ}$  and disappears upon heating to  $510^{\circ}\text{C}$ ) and limits the maximum possible metamorphic temperature to  $200^{\circ}\text{C}$ . The lower percentage of kaolinite in the Tone Fm. may be due to

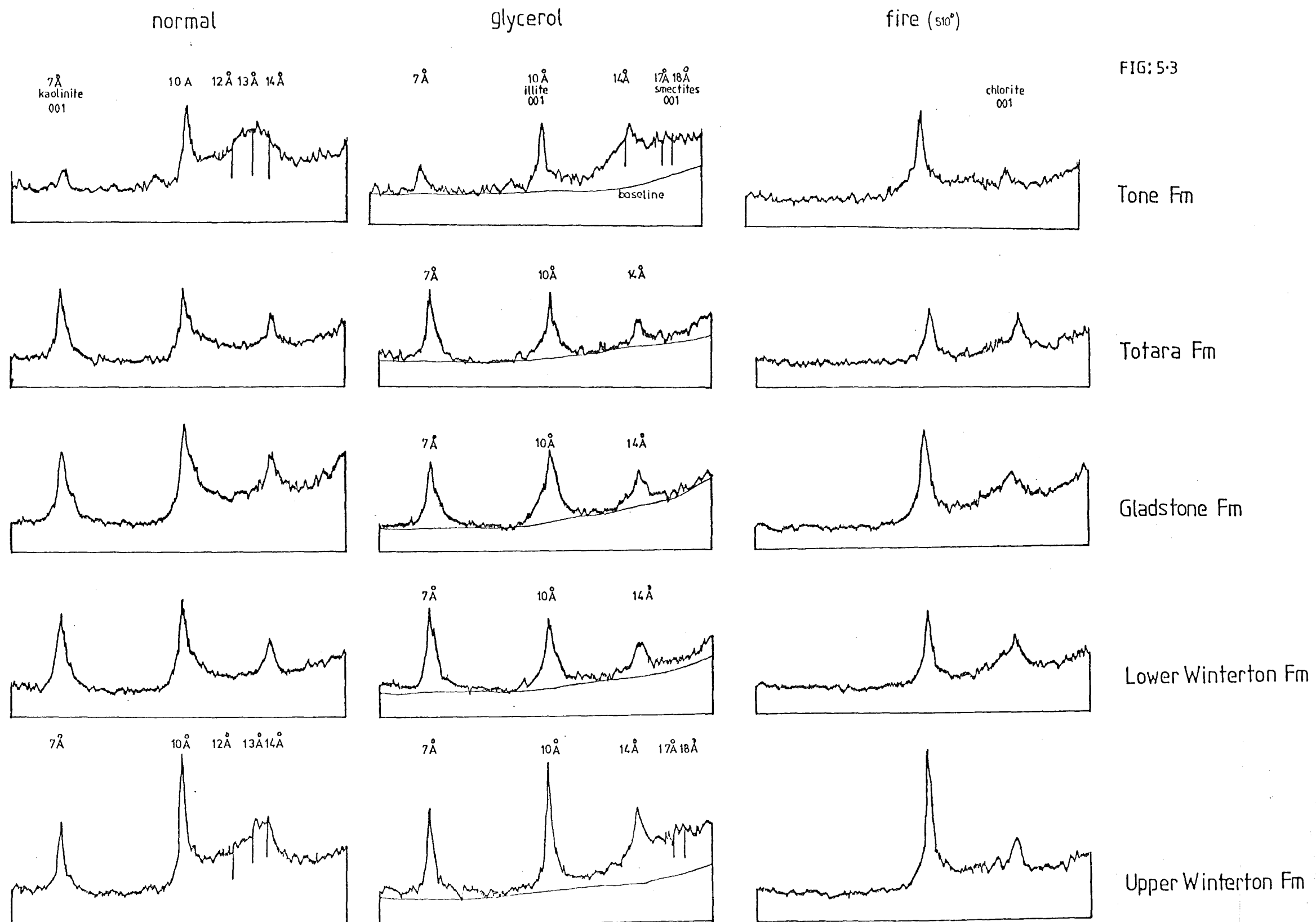


FIG. 5.3

Figure 5.4

## Clay mineralogy of the Mudrocks

Formation	Chlorite	Illite	Kaolinite	Smectite (mixed layer)
Upper Winterton	15%	60%	15%	10%
Lower Winterton	17%	70%	12%	-
Gladstone	17%	65%	18%	-
Totara	22%	60%	18%	
Tone	15%	58%	9%	18%

proportions calculated using Method of Griffin  
in Canner (1971)

its deeper water environment of deposition.

Illite is the most abundant clay mineral in the samples. A comparison of the crystallinity index (De Segonac 1970) from the illites suggests that the muds of all the Formations were about the same metamorphic rank because no systematic differences were apparent.

Chlorite appears poorly crystalline in the formations of the Middelhurst succession (fig. 5.3) but it is uncertain whether chlorite is detrital or secondary (low temperature secondary chlorite is commonly a disordered Type-I, Hays 1970).

In summary, although much more detailed work on the clay minerals remains to be done, the Middelhurst succession clay mineral assemblage is remarkably similar in mineral percentage and crystallinity. Therefore, there is no evidence to suggest that a metamorphic grade is missing between the Tone Fm. and overlying rocks.

#### b) Sandstones

The sandstones are more susceptible to burial metamorphic reactions because of their interaction with migrating fluids. The mineral assemblages are grouped into three zones (fig 5.2a).

The metamorphically most mature zone comprises well indurated rocks (Zone 1, fig 5.2a) and contains metamorphic zeolites which occur only in discrete solution veins or pores (fig 5.5a). This morphology may indicate that the veins and avenues of secondary porosity contained solutions significantly hotter than the rest of the rock, for metamorphic type zeolites are not present elsewhere in the rock. Two types of metamorphic zeolites were recognized: the first is subhedral, has one cleavage (always in the fast direction),

a small (+) 2V, an RI well below quartz, and parallel extinction; the second zeolite had two distinct cleavages, inclined extinction and a large 2V. The first zeolite mineral is interpreted as heulandite, the second was interpreted as laumontite on the basis of its optical axis orientation (D. Shelley pers.comm.). Zone 1 also contains zeolites which are confined to volcanic protoliths (fig 5.5b); these zeolites have a fibrous or cotton-like habit, an RI below canada balsam, may be length fast or slow or both, and have parallel to slightly inclined extinction. From these optical properties the zeolites are interpreted as members of the natrolite group (Deer, Howie, and Zussman 1966) and possibly mordenite. The significance of these zeolites is uncertain but similar zeolites are known to occur diagenetically (Hay and Shepard 1977). Zone 1 also contains secondary chlorite, which may also fill solution pores.

Zone 2 rocks are moderately well indurated and contain diagenetic zeolites and secondary chlorite but no metamorphic zeolites. Zone 3 rocks are mildly indurated and lack both secondary chlorites and metamorphic zeolites but do contain very small zeolites which occur confined to protoliths, but I was unable to identify them.

Significantly, the metamorphic mineral zones have no relationship to the depositional stratigraphy of the Winterton River area. The heulandite-laumontite vein metamorphism clearly post dates the deposition of the Middelhurst Succession. Since the sandstones of Zone 3 are poorly lithified, it is unlikely that the Gladstone Fm. or Lower Winterton Fm. had significantly more overburden in the past than they do now. Many studies of burial metamorphic successions have discovered

Fig. 5.5b:

fibrous natrolite group (scolecite?)  
zeolites in a volcanic protolith  
(diagenetic).

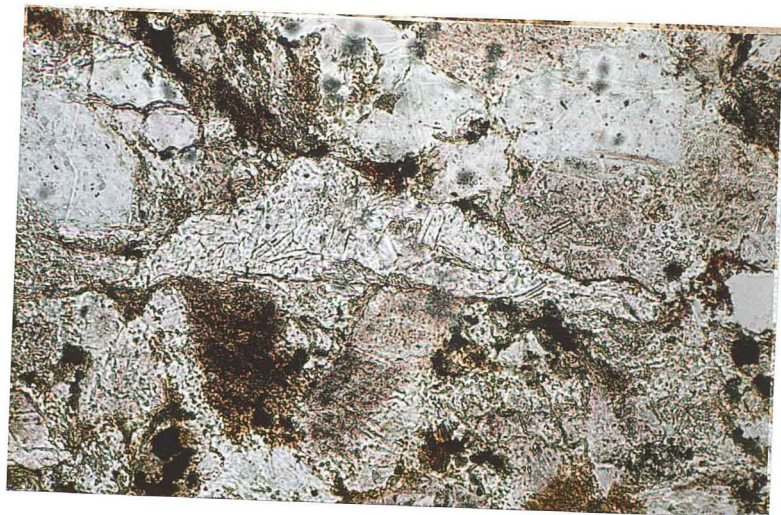
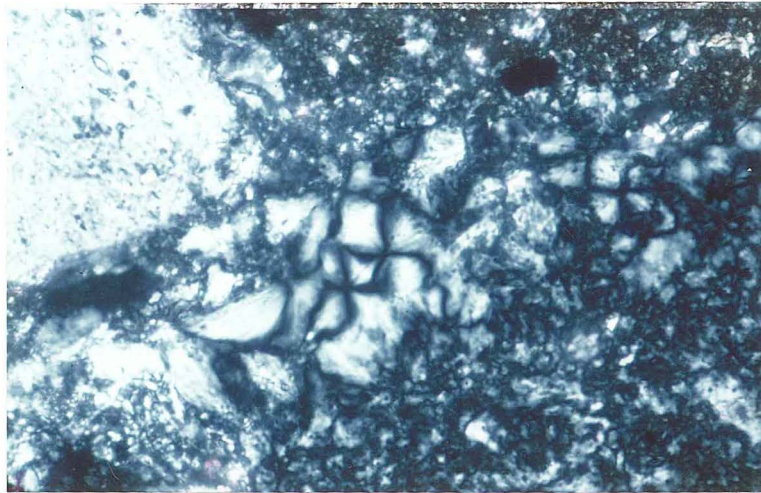
X100 Upper Winterton Fm.

Fig. 5.5a:

metamorphic type zeolite (laumontite?)  
filling a micro vein (note the well  
developed cleavage)

X40 Gladstone Fm.





heulandite-laumontite grade metamorphism in rocks which were once buried at least to 5 Km deep (Dickenson et al 1969, Stewart and Page 1974, Boles and Coombs 1977). The presence of heulandite-laumontite zeolites in rocks which probably have been buried only about 2 Km suggests an abnormally high geothermal gradient. The most likely cause of elevated temperatures is the intrusion of the inland dyke swarm, which is particularly intense in the Winterton River area (see Map 2). The intrusion of the dykes may have produced a hydrothermal convection system of ground water which produced the metamorphic zeolite veins. A similar metamorphic aureole related to a dyke swarm has been described in Iceland by Walker (1960).

The interpretation that the metamorphic overprint by the dyke swarm is restricted to permeable zones within the rock is supported by other evidence. Albitization in Zone 1 rocks as a whole appears mild (based on optical extinction angles, R.I., and X.R.D.). As mentioned previously, albitization is commonly severe in heulandite-laumontite grade metamorphism. Potassium feldspars are also present (both in sandstones and muds) which may suggest very low burial metamorphic grade. The clay mineral assemblage of the mudstones lack well ordered interlayer smectites which are usually well ordered (Hoffman and Hower 1979) in heulandite-laumontite grades. Thus, the bulk rock characteristics suggest that the metamorphic rank prior to the intrusion of the dyke swarm of all formations in Zone 1 was lower than heulandite-laumontite facies.

## 2. The Middelhurst Cr. - Castle Cr. Area

In order to evaluate the proposed metamorphic unconformity, an area should be examined which has a minimal thermal overprint from the dyke swarm. The dyke swarm intensity decreases significantly to the NW (see Map 2) and the mineral assemblages and metamorphic zones of this area are shown in fig 5.2b.

Mudstone clay mineralogies from the Upper Winterton Fm. and the Tone Fm. were essentially the same as in the Winterton River area and do not suggest a missing metamorphic interval between the Tone Fm. and overlying units.

The sandstones of the Tone Fm. (Zone A) are well indurated, contain diagenetic zeolites similar to those in Zone 1, contain secondary chlorite, but lack the metamorphic zeolites present in the Winterton River. The rocks were examined for prehnite and pumpellyite; although many feldspars contain small prehnite-like crystals, these all proved to be length slow and are probably sericite. XRD patterns of minerals from the sandstones also did not indicate prehnite or pumpellyite. The sandstones in Zone B are moderately to mildly indurated, lack secondary chlorite, but do contain extremely fine grained diagenetic zeolites which I was unable to identify (see slide 9275).

Thus, although there is a marked induration difference between the Tone Fm. and overlying rocks in the northwestern part of the outlier, neither the mudstone clay mineralogies or the sandstone mineralogies indicate that there is a significant change in metamorphic rank from Torlesse-like to overlying rocks. Although more work on the metamorphic grade

variations within the Tone Fm. are needed, the present evidence suggests that the rank of the Tone Fm. prior to the deposition of the covering strata was below heulandite-laumontite grade.

The significance of the induration difference between the Tone Fm. and the overlying Upper Winterton Fm. and/or Castle Creek Conglomerate in the northwestern part of the outlier is uncertain. In the Gulf Coast, Wilcox Fm. sandstones above the overpressured zone have higher acoustic velocities than sandstones below the zone; this has been interpreted by McBride (pers.comm.) and oil company geologists as an induration difference due to rapid dewatering of the sandstones above the overpressured zone. Similar observations have been made by geologists working in the Niger Delta (R.A. Cook pers.comm.). If rapid dewatering can cause significant induration differences in continuous sedimentary sequences, one cannot conclude that induration differences alone imply a metamorphic break. The induration of the Tone Fm. may be completely a response to deformation at relatively shallow burial depths; the contrast in induration between the Tone Fm. and overlying Upper Winterton or Castle Creek Conglomerate may thus be entirely a function of degree of deformation and have no burial metamorphic significance.

## DISCUSSION

If a regional unconformity separates the Tone Fm. from overlying rocks, how large a metamorphic break would one expect to see? The regional unconformity concept demands that a significant period of erosion has taken place ... how much would be significant? In <sup>orogenic</sup> continental areas one would

expect the erosion to be many kilometers deep, so that metamorphic rocks (at least prehnite or lawsonite grade) would be exposed. In volcanic areas, one would expect only the roots of the volcanic chain to be exposed (i.e. granites). However, there cannot be regional erosion across the entire continental margin at the same time for very long because there would be no place to deposit the enormous volume of sediment moving off the continent. Thus it seems to me that regional erosion surfaces which erode kilometers off the continental margin are rare. It is possible on the continental margin to have local, tectonically significant unconformities which do not show any marked change in metamorphic grade across the contact (in the Makara basin mildly indurated Neogene rocks rest with angular discordance on deformed Paleogene rocks without a metamorphic break, G. Van der Lingen pers.comm.).

In conclusion, there is no demonstrable metamorphic facies or grade missing between the Tone Fm. and overlying rocks; there is, however, a local induration difference. The tectonic significance of the induration difference is uncertain. The lack of a metamorphic break suggests that any erosion period separating Torlesse-like and covering strata did not remove a significant thickness of the Tone Fm.

## PART II: DIAGENESIS

### INTRODUCTION

The diagenetic history of the Middelhurst Succession appears to have two distinct phases: a prograding series of diagenetic events which culminated with the development of zeolite veins, and a retrogressive carbonate replacement phase. The first phase consisted of: a) processes which altered or destroyed detrital grains and original bedding fabrics, and b) processes which produced new structures and fabrics. The second phase comprises carbonate cementation and/or replacement of the detrital grains.

All the discussion concerns sandstones, since mudstones are less suited for microscope study; however, it is recognized that sandstone diagenesis is genetically related to the diagenesis of mudrocks.

### PHASE I

Phase I can be separated into two overlapping stages. Stage 1 is an early burial period dominated by compaction, loss of permeability due to the mechanical flattening of grains, dewatering, and the disruption of internal stratification by liquefaction. Step 2 involves the migration of new fluids into the rocks and the reactions between the fluids and the detrital components, producing solution veins, complex [episodes of] feldspar dissolution and recrystallization, and secondary minerals such as clays and zeolites.

## 1. Disruption and Destruction of Original Grains and Fabrics

The alteration of primary features can be seen on the grain, bed, and intra formational scales. The processes of disruption appear to have their roots in the mechanical and chemical interactions between compacting sediments and the ~~inter~~ pore fluids.

### a) disruption of detrital grains

The porosity and permeability of the Middelhurst succession sandstones was reduced by mechanical flattening and squashing of detrital grains. Weathering of feldspars, micas, and the replacement of igneous fragments contributed to the overall compaction of the sediment by making some grains more ductile. Weathering (either pre or post depositional) of feldspars did make some of the grains mildly ductile, which caused a closer packing arrangement (fig. 5.6). Of the micas, biotite was the most commonly weathered, but both weathered and fresh biotites were ductile. In situ weathering of biotite appears to have effected the permeability of the sandstones by contributing components to secondary matrix. The volcanic clasts showed a variety of post depositional alterations. One type was the conversion of the grain into a chert-like aggregate, which sometimes retained the original feldspar microlites (fig. 5.7). In fig. 5.7 the altered grain, originally well rounded, appears to have been indented by adjacent grains. This softening of the grain may have occurred during the alteration. Zeolite alteration is common but occurred after most of the compaction took place. Fig. 5.8 shows a zeolite filled grain which is well rounded but only mildly indented by neighbouring grains. On the whole, the

Fig. 5.6:

weathered feldspar (w) mechanically deformed by surrounding, relatively unweathered feldspar grains (also note feldspar overgrowths).

X125 Lower Winterton Fm.

Fig. 5.7:

volcanic clast altered to a chert-like aggregate; note remnant feldspar microlite (L) and dark, weathered, mafic minerals. Some squashing of the grain has taken place.

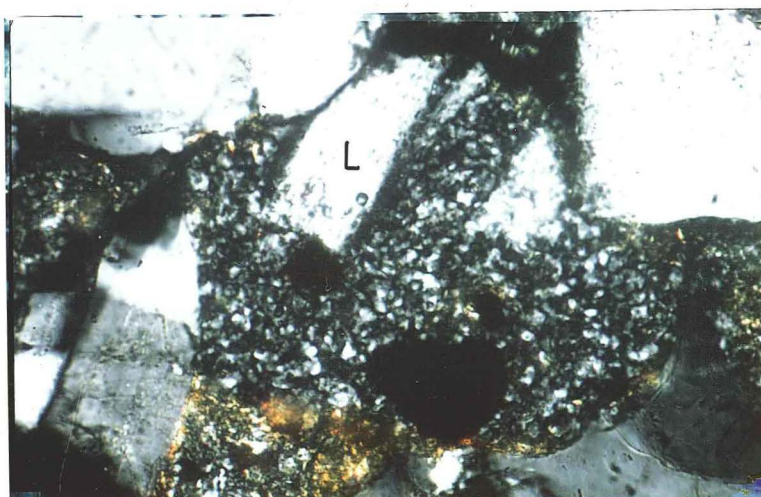
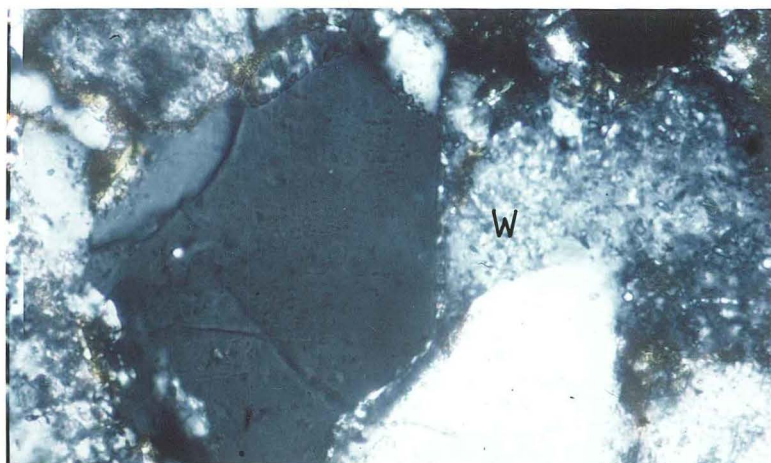
X100 Tone Fm.

Fig. 5.8:

volcanic grain altered to natrolite family zeolites; the grain has retained its well rounded shape so alteration appears to be post compaction.

X63 Gladstone Fm.





contribution of grain weathering and alteration to the overall degree of ductility in sandstone grains was subordinate to primary ductility of many of the lithic clasts.

Lithic grains, particularly those of sedimentary origin, are commonly flattened and squeezed into pore spaces between more competent grains (fig. 5.9). Micaceous grains behave similarly. Qualitatively, there appears to be an increase in flattening downwards. In the poorly lithified Castle Creek Conglomerate, many of the grain contacts are tangential, some grains float, and some have long contacts. However, even in the Upper Winterton Fm., although the sandstones are moderately lithified, most of the grain contacts are long and most of the pore space appears to have been plugged by ductile grains (fig. 5.10). Among feldspar grains, the proportions of concavo-convex grain contacts increases relative to long contacts from the Upper and Lower Winterton Fms. to the Gladstone, Totara, and Tone Fms. Sutured grain contacts also increased downwards; however, without cathodoluminescence it is difficult to ascribe the sutures to overgrowths or pressure solution. In summary, there appears to have been considerable compaction of the sandstones at relatively shallow depths. This agrees with recent work by Galloway (1979) who shows that lithic sandstones may compact at rates equal to that of their surrounding mudstones.

The fast rate of compaction and sandstone inhomogeneity combined to produce lamellar and lenticular zones of intergranular porosity in the sandstones. The sandstones are composed of layers which alternate between being feldspar-quartz rich and lithic rich. The zones rich in mechanically competent grains (i.e. quartz and feldspar) retained their

Fig. 5.9:

ductile and competent lithic grains; note how pore spaces have been completely filled by squashed lithic fragments

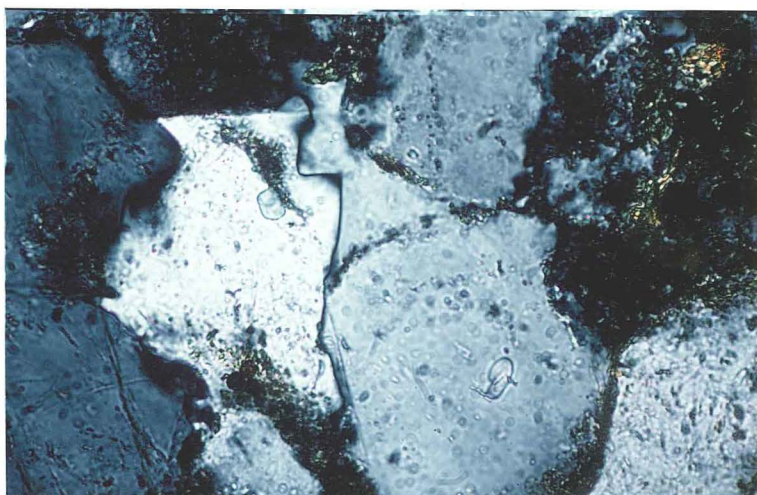
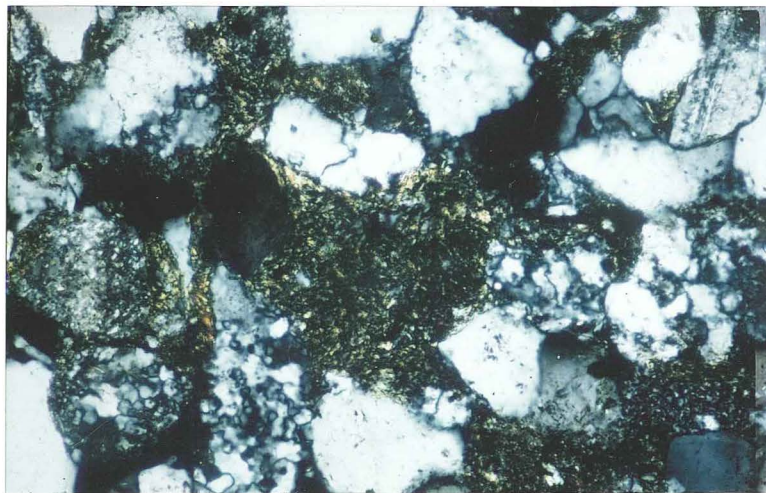
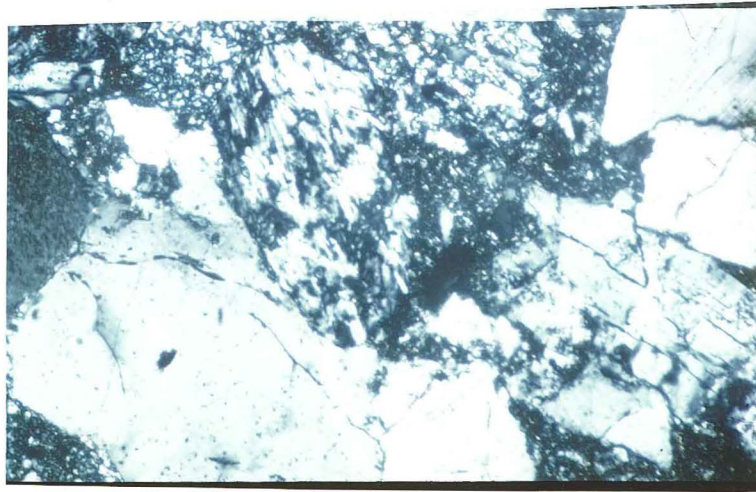
X50 Gladstone Fm.

Fig. 5.10:

close packing in the Upper Winterton Fm; again, pore space has been greatly reduced by compaction.

Fig. 5.11:

feldspar overgrowths in a feldspar rich horizon within a sandstone; the intergranular porosity was preserved during compaction by the lack of ductile lithic clasts.





porosity better than zones rich in ductile lithic grains. This localization of porosity is reflected by the abundance of mineral overgrowths and cements in competent grain rich zones (fig. 5.11) and the absence of such secondary features in lithic rich zones. Since relatively high intergranular porosity was restricted to certain lenticular zones, the overall permeability must have been low. Work on lithic sandstones by Galloway (1974, 1979) suggests that compaction may reduce porosity from 1000 to 10 millidarcys over a shallow 300-1500 m. burial depth.

This rapid compaction leading to low effective porosity has an important consequence. During burial, water liberated from compacting mudstones escapes to lower pressure regions via more permeable sandstones (Curtis 1978, Hays 1979). However, since permeability was restricted, the overall permeability of the Middelhurst succession sandstones may have been too low to allow the fluids to migrate at a rate which maintained a normal fluid-pressure gradient. Thus, excess pore pressure resulted. The degree of overpressuring in the upper Middelhurst succession was probably never large because the total vertical stress (a function of overburden) was apparently never great. Excess pore pressures were sufficient, however, to cause some disruption of internal stratification.

#### b) disruption of internal stratification

Individual sand beds have various styles of internal deformation such as flame structures, injection structures, contorted laminae, and microfaults.

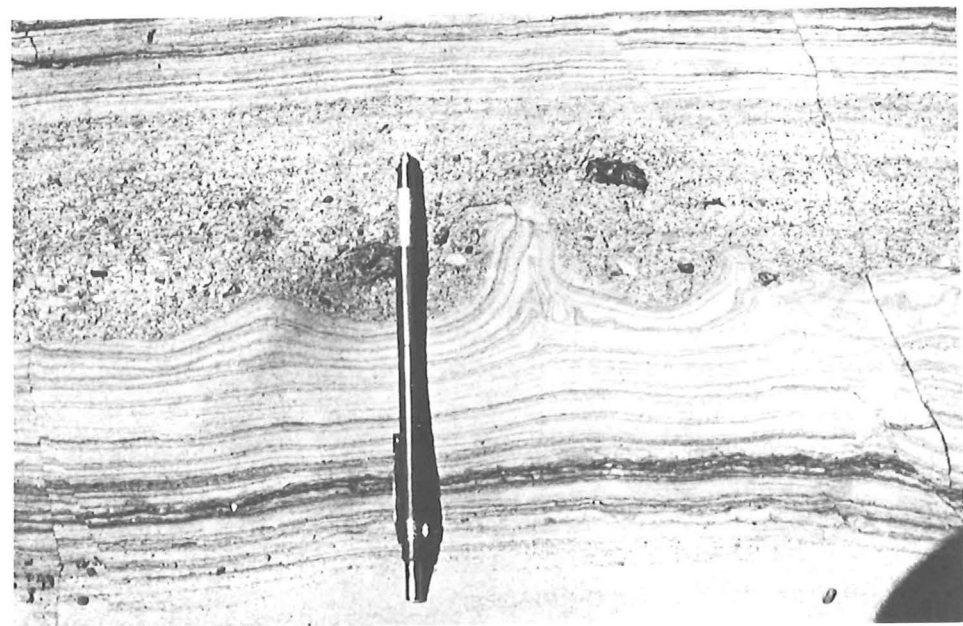
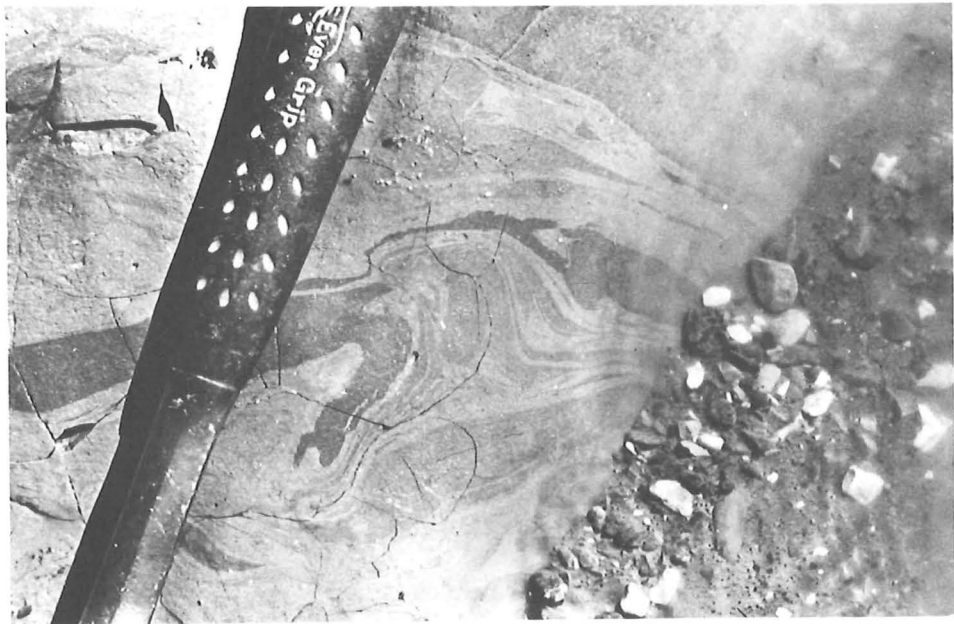
Figures 5.12 and 5.13 show contorted laminae in the Tone Fm. and Upper Winterton Fm. respectively. These contortions are distinct from convolutions (which also occur in the Middelhurst succession) because the contortions effect several laminated beds while convolutions effect only a horizon within an undisturbed bed. Convolutions may form by penecontemporaneous disruptions of ripples; the contortions, however, are interpreted as a post depositional feature. Figure 5.14 shows flame structures which are less common. Both these features are interpreted as caused by partial liquefaction of the sediments due to excess pore water pressure (Blatt et al 1980); the presence of these structures suggests the sandstones of the Tone, Totara, Gladstone, Lower Winterton, and Upper Winterton Fms. had difficulties accommodating the volume of water which migrated into them.

Mud and sand injection structures were rare in the upper Middelhurst succession, but were more common in the significantly more deformed Tone, Totara, and Gladstone Fms. In the Tone and Totara Fms, mud and sand occasionally intruded up small microfaults. Mud was also squeezed away from the hinges of folds into lenses or welts; this plastic behaviour suggests soft sediment deformation. In the Tone Fm., flames of very fine grained sand intrude into fine grained sandstone in compound sand beds. Some very fine grained sand dykes apparently intrude from one sand body into another. At several localities, the Tone Fm. has massive sandstones with islands of preserved laminations in an otherwise structureless bed. Although bioturbation may produce this effect, trace fossils in general are so rare that this is an unlikely explanation. An alternative explanation would

Fig. 5.12:  
contorted laminae in the Tone Fm.

Fig. 5.13:  
contorted thin beds in the Upper Winterton Fm.

Fig. 5.14:  
flame structures, Upper Winterton Fm.;  
note also the microfaults.





attribute the internal disruption to liquefaction in response to folding and mild overpressuring.

All the formations contain annealed microfaults which offset the laminae with small (several millimeters) to moderate (several centimeters) displacement (figs. 5.15, 2.3). Although calculations suggest that microfaulting may be caused by excess pore pressures (Palcrauskas and Domenico, 1980), the microfaults present in the Middelhurst succession are probably not of this origin because the succession is not nearly buried deep enough to produce the pressures required. The microfaults are mostly normal faults (figs. 5.14, 5.15) but reverse faults also occur (fig. 5.16). Thomson (1973) described microfaults in sandstones and attributed the faults to slumping. Thomson's faults are distinct from Middelhurst succession faults, however, in their being restricted to the base of the sand beds. The Middelhurst succession microfaults may originate either as synsedimentary readjustments of the sand beds to gravity or as a response to the intrusion of the dyke swarm. In either case, the annealed character of the faults suggests that they developed before lithification.

In summary, the presence of contorted laminations, flame structures, and injection structures suggests that the sandstones had low permeability and were in part deformed by liquefaction. The plastic behaviour of the mudstones indicates that much of the deformation of the Tone, Totara, and Gladstone Fms. occurred before lithification. Despite their brittle look, the annealed nature of the microfaults also suggests that the microfaults are a pre-lithification feature.

### c) Destruction of Internal Stratification

Thick sandstones (2-10m) in the Gladstone and particularly the Tone Fm. were almost always structureless and surrounded by thin bedded alternating sandstone and mudstone sequences with preserved laminations. Thick, lenticular, massive sandstones have been described elsewhere as gravity flow deposits, their massive texture being depositional rather than post depositional. The reason for believing the thick sands of the Tone Fm. have been modified is that occasional carbonaceous layers visible in hand specimen show parallel laminations, implying that originally the thick beds were at least partially laminated.

The cause of this "homogenization" of sandstone beds is uncertain, but similar types of thick, massive sandstones surrounded by internally stratified mudstone-sandstone interbeds are reported in the Tesnus Fm. (McBride 1970), the Burnett Fm., Fiordland (Chris Ward pers.comm.), and in other parts of the Torlesse terrane (Andrews et.al 1976). Mechanisms which may contribute to the destruction of sedimentary structures include:

1. solution and recrystallization
2. internal compaction and differential compaction of surrounding mudstones
3. overpressuring
4. deformation and plastic flow
5. bioturbation

I feel that the one aspect which separates the thick massive sandstones from the thin sandstones is that the thick

sandstones made much better aquifers and consequently had a greater volume of fluid moving through them. This makes the thick sandstones more susceptible to dissolution and overpressuring than thin sandstones. The destruction of internal stratification is an interesting problem which needs more work.

#### d) Disruption of Bedding

I have suggested that mild excess pore pressures contributed to the local disruption of internal stratification by liquefaction. The internal deformations within the upper Middelhurst succession support this hypothesis. In the upper Middelhurst succession, there are no mud lumps, mud diapirs, or mud swells which are usually present in heavily overpressured sequences. There are, however, small growth faults (fig. 3.26) which are thought to occur during rapid sedimentation under the influence of gravity and lubricated by zones of mildly overpressured mud (Crans et al 1980). Other larger scale disruption structures such as slumps or soft sediment folding (fig. 5.17) appear to be gravity related.

In the lower Middelhurst succession, despite folding and faulting, there also is an absence of mud tectonics, although mud may behave rather plastically. The Totara and part of the Gladstone Fm. are allochthonous and may have slid on mildly overpressured mud zones. Thus, the Middelhurst succession displays features consistent with only mild overpressuring and intra formation, larger scale, bed disruption appears to be primarily gravity influenced.

## 2. New Structures and Fabrics

### a) Fault Fillings

The ability of the sandstones in the Middelhurst succession to transmit fluids was improved by the generation of the microfaults mentioned earlier. These faults are commonly filled with an authigenic matrix which enhances the faults' visibility (fig. 5.15) and contributed to the annealed character. The presence of a void filling secondary matrix suggests that the microfaults were conduits for fluid migration which were finally cemented up. The Totara Fm. also has these fault-vein fillings (fig. 2.3) but it is not known whether these faults were cemented before or after emplacement of the Totara Fm. The presence of these microfaults may have contributed to the array of dissolution textures and secondary minerals by increasing the permeability of the sandstones and thus improving the circulation of ground fluids.

### b) Solution Veins

In the lower Middelhurst succession, dark dendritic veins occur (fig. 5.18). In hand specimen, the veins may be braided and each major vein has tiny tributaries. Under the microscope, the veins appear as zones rich in matrix-like material. These zones differ from the normal rock fabric in that the grains appear to have tangential or floating grain contacts in the sea of matrix (fig. 5.19). The matrix-like pore fillings interconnect to form "ribbons" which weave between the detrital grains (fig. 5.20). Rather than a fracture filling, the porosity appears to be wholly intergranular. Although dissolution of grains is not restricted

Fig. 5.15:

microfaults offsetting laminae in a sandstone (Lower Winterton Fm.); note how some of the faults die out upwards and so appear to be synsedimentary.

Fig. 5.16:

thrust microfaults in the Upper Winterton Fm.

Fig. 5.17:

soft sediment folds, Upper Winterton Fm.; note the undisturbed beds on top.

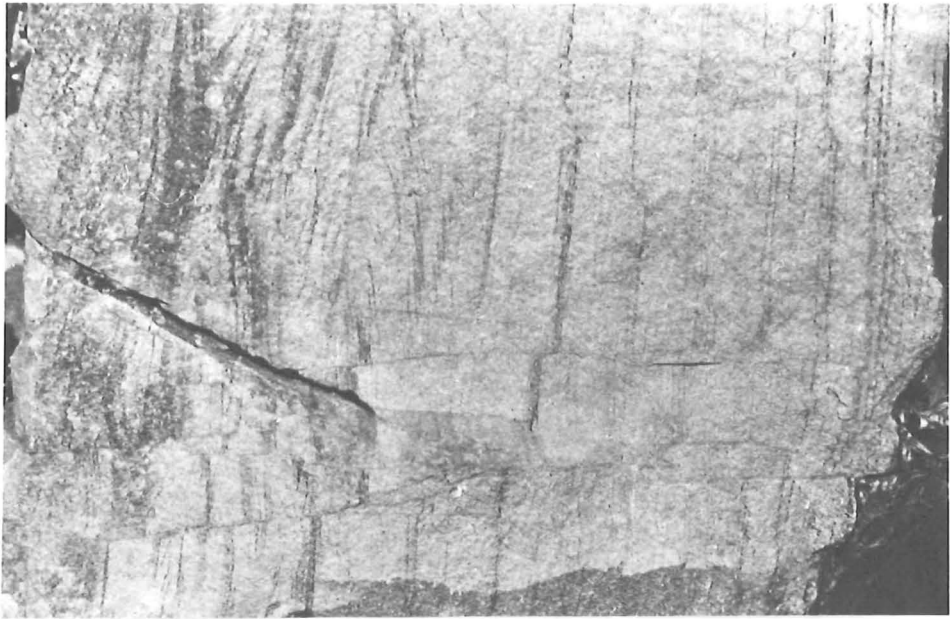


Fig. 5.18:

solution veins (or zones) filled with dark,  
secondary, matrix-like fillings, Gladstone Fm.

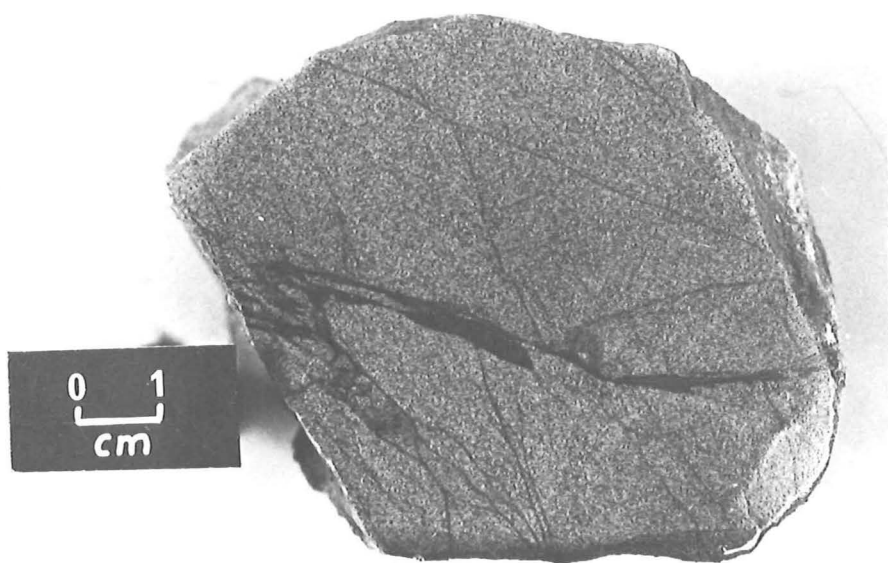




Fig. 5.19:

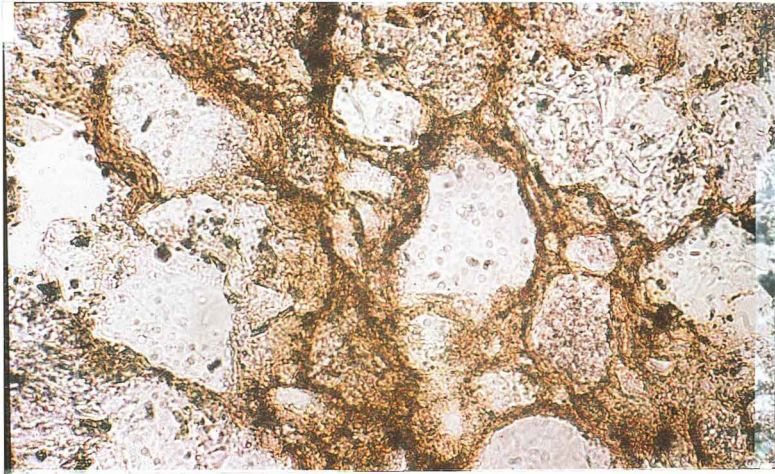
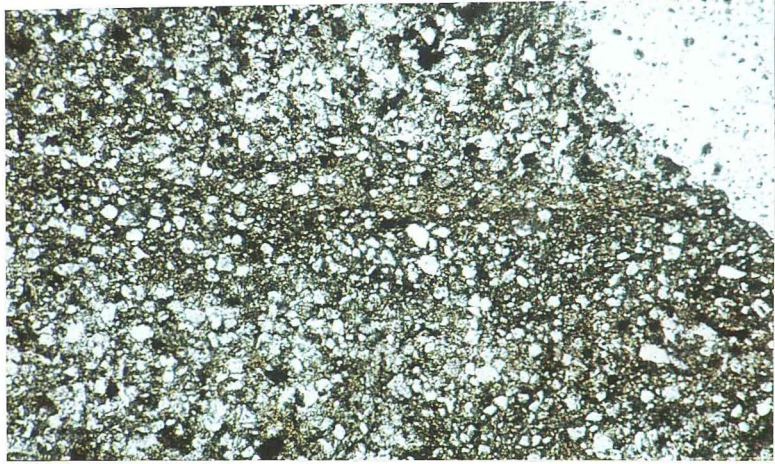
solution vein (or zone); note how the detrital grains appear to float in a matrix rich zone.

X10 Totara Fm.

Fig. 5.20:

ribbon-like bands of dark secondary matrix running between detrital grains; note how jagged the grain boundaries are - due to solution.

X100 Gladstone Fm.



to these veins, dissolution is quite severe. Fig. 5.21 shows a clear example of corrosion of a feldspar grain; generally the grains in the solution veins have jagged and embayed edges (fig. 5.20), suggesting that the solution veins were formed by a period of intense corrosion followed by the precipitation of a matrix-like pore fill. Feldspar overgrowths do occur in these solution veins and may be unusually large; feldspar overgrowths are also corroded and predate the matrix pore fill. This suggests that the solution veins have had a complicated history of corrosion and overgrowths before the final episode of matrix precipitation. Fig 5.22 shows at least two periods of feldspar overgrowths; the first overgrowth (A) has a lower R.I. than the parent grain (B), but a higher R.I. than the larger feldspar overgrowth (C).

The matrix-like pore filling is similar to the matrix-like pore fillings of the microfaults and thus may be related. The solution veins predate the zeolite veins but appear to be related to them. Since Galloway (1979) noted that diagenetic activity is related to geothermal gradient, the solution veins may reflect the high geothermal gradients introduced by the intrusion of the dyke swarm.

#### c) Patchy Secondary Porosity

A second style of intergranular dissolution occurred, characterized by a patchy, non vein appearance and an absence of secondary, matrix-like pore fillings. Grains in the patches are corroded from the outside in, reflecting the intergranular nature of the reacting fluids. This patchy corrosion apparently alternated with periods of feldspar overgrowths.

Fig. 5.21:

corrosion of a feldspar grain in a solution vein; the dissolution has been influenced by the cleavage.

X100 Gladstone Fm.

Fig. 5.22:

several episodes of solution and feldspar overgrowths; the original detrital grain (B) has an initial overgrowth (with a lower R.I.) at (A) and a second overgrowth at (C).

X160 Lower Winterton Fm.

Fig. 5.23:

corrosion of a mafic mineral (A) and low R.I. feldspars (B) and replacement by albite (C) and feldspar overgrowths (D).

X63 Gladstone Fm.



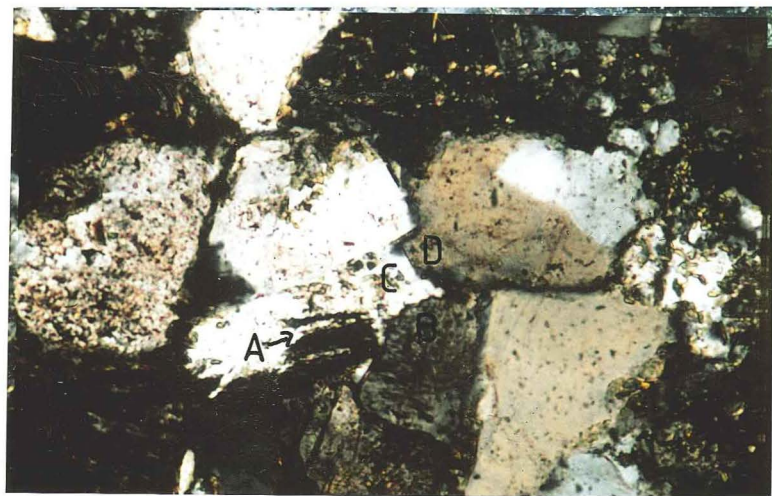
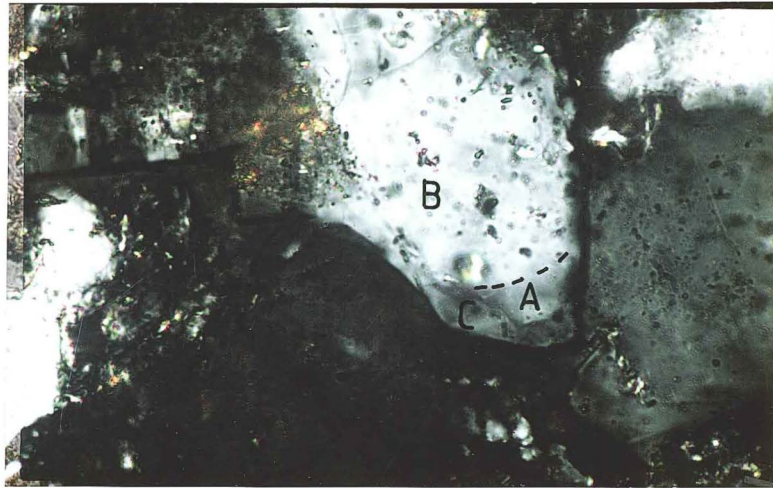
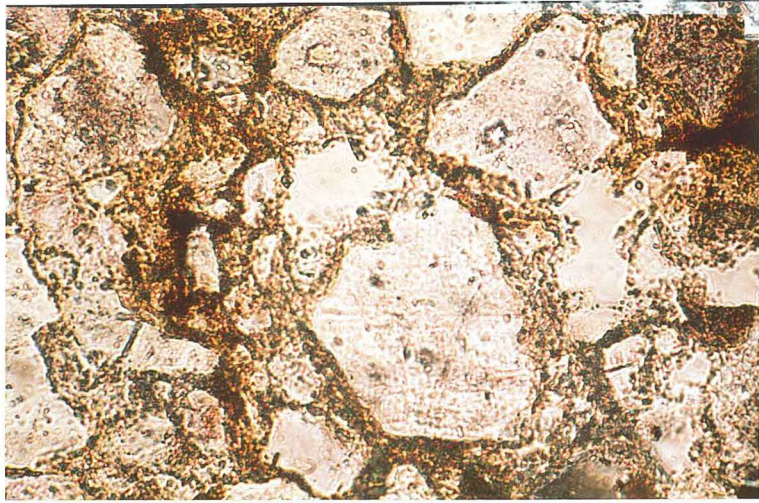


Fig. 5.24:

corrosion of a detrital amphibole and replacement by albite.

X160 Tone Fm.

Fig. 5.25:

corrosion of an alkalie feldspar (A) and replacement by a higher R.I. feldspar (albite) in optical continuity with the original grain.

Fig. 5.26:

a zeolite vein (metamorphic) cutting across a feldspar grain.

X63 Gladstone Fm.

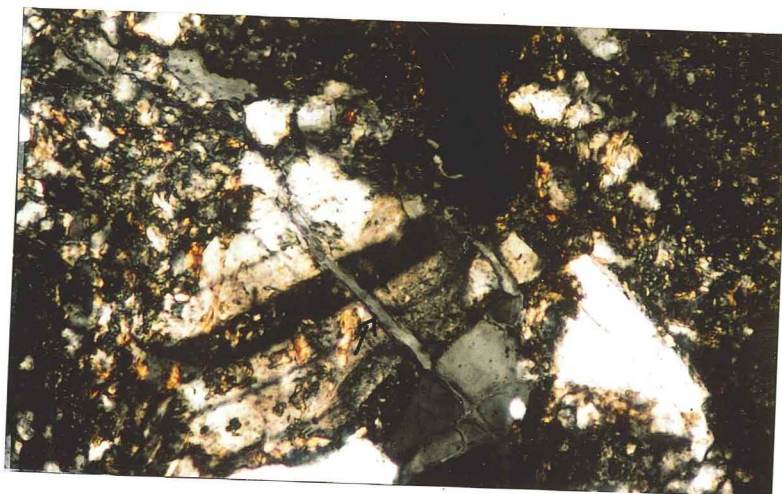
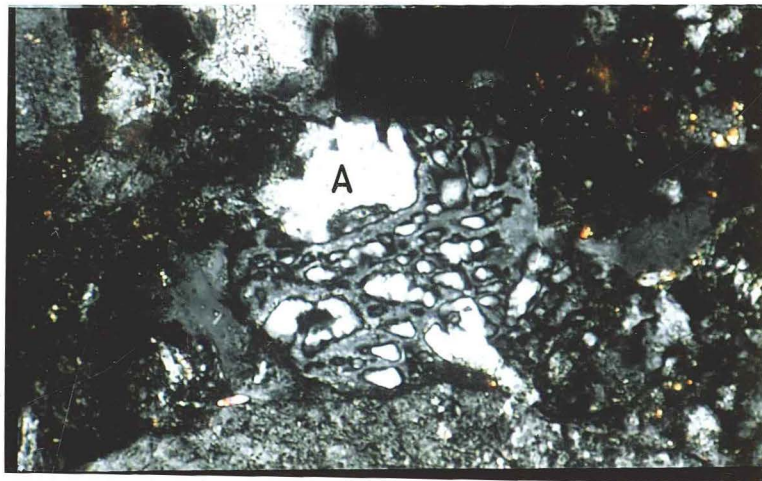
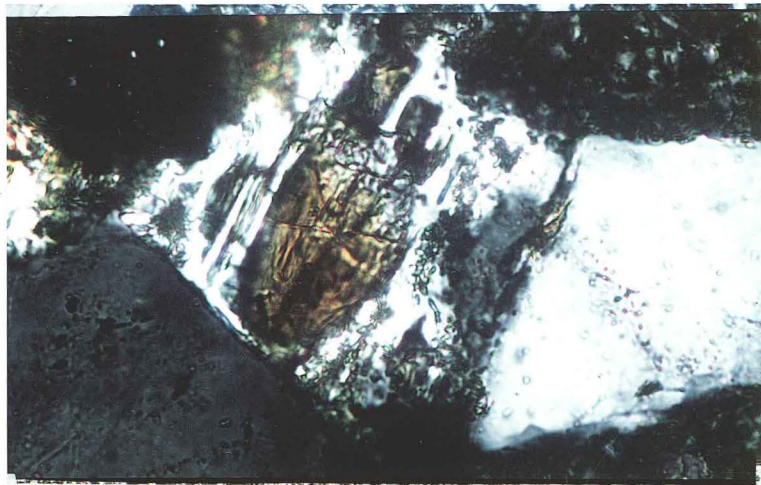


Figure 5.23 shows corrosion of a mafic mineral (a) and a low R.I. feldspar (B). The resultant vug is filled by a higher R.I. feldspar (albite) and by overgrowths of another feldspar (D). Figure 5.24 shows a similar sequence of corrosion and feldspar replacement in the resultant vug. Figure 5.25 shows corrosion of an alkali feldspar (A) and subsequent replacement by another feldspar (albite) (B) in optical continuity with the original grain. This patchy secondary porosity is easily recognized in the Basal Lower Winterton Fm. and the Gladstone Fm., where primary porosity would have been better preserved than in the Totara or Tone Fms. The zeolite veins cut across these textures, and so post date them. Similar textures were observed in sandstones of the Split Rock Fm. (author's own observations) and so patchy secondary porosity may be a common feature of feldspathic-lithic sandstones under normal conditions.

#### d) Zeolite Veins

The zeolite veins are distinct from the other styles of secondary porosity in filling vugular rather than intergranular porosity. In figures 5.26 and 5.27, zeolite veins cut across individual grains and may fill relatively large voids. Figure 5.28 shows a large vug filled with zeolite (Z); feldspar grains (f) show well developed overgrowths around all their exposed surfaces, suggesting the vug was already present when the overgrowths grew. At (c) in figure 5.28, the feldspar overgrowths were corroded just before the precipitation of zeolite. Thus, these vugs have had a complicated history of dissolution and secondary overgrowths in much the same style as the solution veins and the patchy



Fig. 5.27:

metamorphic zeolite filling vugular porosity.

X40 Gladstone Fm.

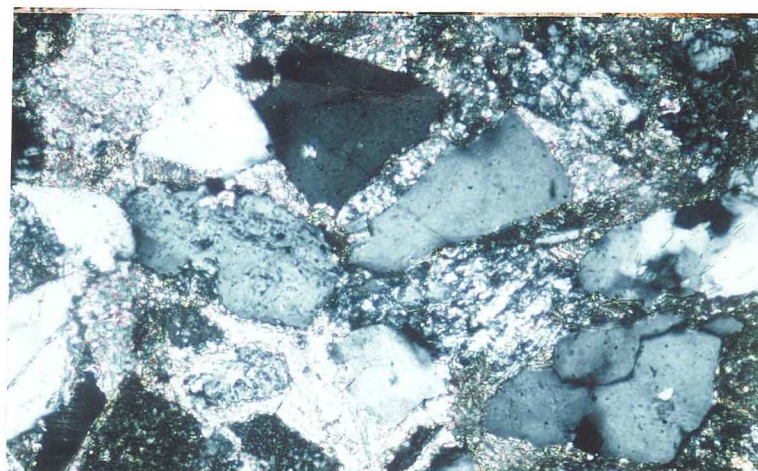
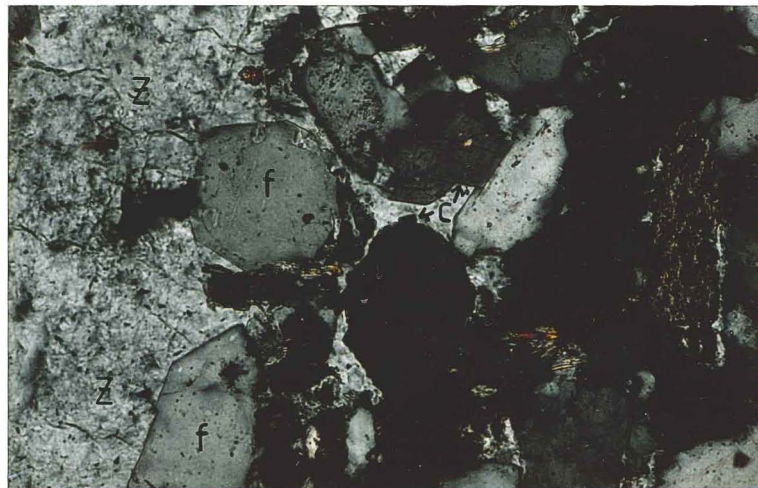
Fig. 5.28:

vug filling, metamorphic type zeolite (Z) (Heulandite);  
feldspar grains with beautiful circumgrain overgrowths  
(f) and corrosion textures (c); note the lack of  
lithic clasts

X50 Lower Winterton Fm.

Fig. 5.29:

carbonate replacement (from intergranular cement,  
Castle Creek Conglomerate.



porosity. The zeolites are not corroded or themselves replaced by feldspar, so zeolite mineralization appears to be the final phase of a complicated history of mineral/fluid interactions. Since the presence of zeolites is best explained by the intrusion of the dyke swarm, the system of solution veins and zeolite veins may reflect the presence of hot fluids circulating in the rocks of the lower Middelhurst succession.

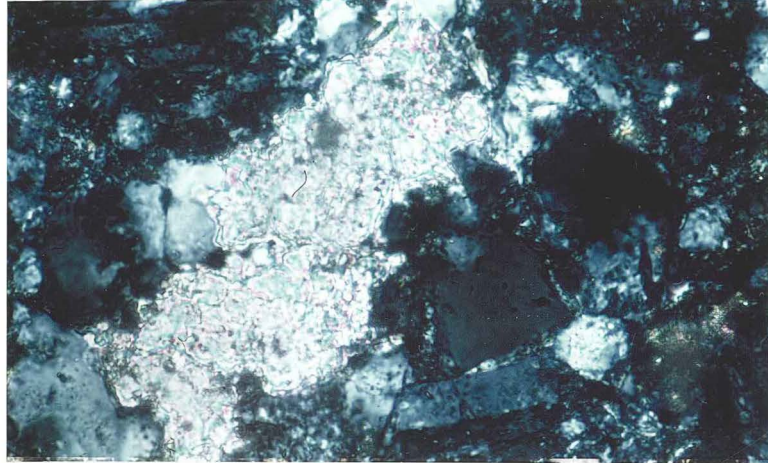
## PHASE II

Phase II began with the uplift and large scale fracturing of the more brittle rocks of the Middelhurst succession during the Kaikoura Orogeny. Fluids moved into the sandstone (via these fractures in the more indurated rocks) and began a new period of mineral dissolution.

### 1. Carbonate Replacement

Fluids rich in carbonate infiltrated the Middelhurst succession and began to replace the detrital components with carbonate. In the mildly lithified sandstones, carbonate replacement appears to originate from intergranular solutions (fig. 5.29), while in indurated sandstones the replacement appears vugular (fig 5.30). In hand specimen, carbonate veins fill joints and fractures which are very common in the Tone Fm. Carbonate replacement textures cut across the feldspar-zeolite solution textures and so clearly post date them. The association of carbonate with the brittle fracture patterns of the Kaikoura Orogeny confirm their retrogressive character.

Fig. 5.30:  
vugular carbonate replacement, Totara Fm.  
X125



## CHAPTER 6: STRUCTURE

STRUCTURAL STYLE AND THE DISTINCTION BETWEEN TORLESSE AND YOUNGER ROCKS1. Introduction

Structural discordance is one of the most common characteristics used by geologists to distinguish Torlesse-like from overlying rocks, as Laird (1980) writes:

"At many places mid Cretaceous rocks overlie an angular unconformity separating highly deformed and indurated, sparsely fossiliferous, older strata from markedly less deformed and indurated more fossiliferous strata of late Albian age. Even where an unconformity is not obvious, the change in deformation and induration is evident and appears to represent a major change in tectonic regime."

The purpose of this section is to describe the structural differences between Torlesse and overlying rocks and discuss their tectonic significance.

2. Structural Style of the Tone Fm.

In a simplified view, the structure of the Tone Fm consists of large scale folds which are offset by faults. The overall largeness of the structures is shown by long ridges of resistant sandstones (fig 2.2) which may crop out along strike for up to 1.5 km (fig 6.1). More detailed mapping is needed to determine the trend of these folds but the strike of the Tone Fm in many areas is consistently between north and east (fig 6.1 also fig 7.1).

On a small scale the rocks of the Tone Fm are intensely

Figure 6.1

Aerial photo showing the long resistant ridges of Tone Fm sandstones; note the change in orientation (scale: 2 /1 mile, lower George River)

Figure 6.6

View of Mt. Lookout from the east; the Lookout basalts are dipping west and northwest towards the Awatere Fault.





deformed; soft sediment structures include sand injection, thin bed contortions, small scale (2 or 3 meters across) folds, and plastic mud flowage. In outcrop, however, the most obvious features are the brittle structures such as joints, fractures, or the literally hundreds of small faults and microfaults which displace individual beds on a scale of millimeters to several meters. The effect of this brittle deformation on the sand rich portions of the Tone Fm can be seen in fig 2.2 where although the sequence is coherent, individual sand beds are badly fractured.

The small scale deformation is locally controlled by lithology. Sand rich, flysch-like sequences may be only moderately dipping ( $40^{\circ}$ ) and relatively undeformed, while mud rich, flysch-like units may be boudinaged and severely folded into tight discontinuous folds.

A simplified view of the Tone Formation's structural style is illustrated in figure 6.2a; how much of the brittle deformation is due to the Kaikoura Orogeny is unknown; the large scale folding and faulting is thought to be pre Motuan deformation.

### 3. Structure Differences in the George River

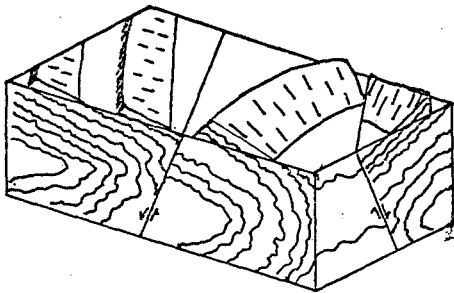
In the George River gently dipping and moderately indurated strata of the Upper Winterton Fm rest with angular discordance upon almost vertical, highly indurated, jointed and fractured Torlesse-like rocks (Tone Fm). Here there appears to be a significant structural break across the unconformity.

### 4. Structure Differences in the Winterton River Area

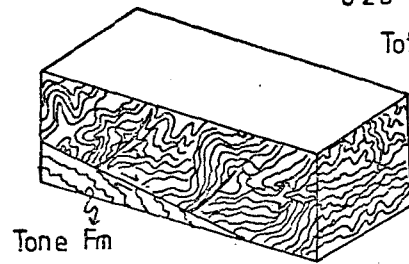
In the Winterton River the stratigraphic section is more



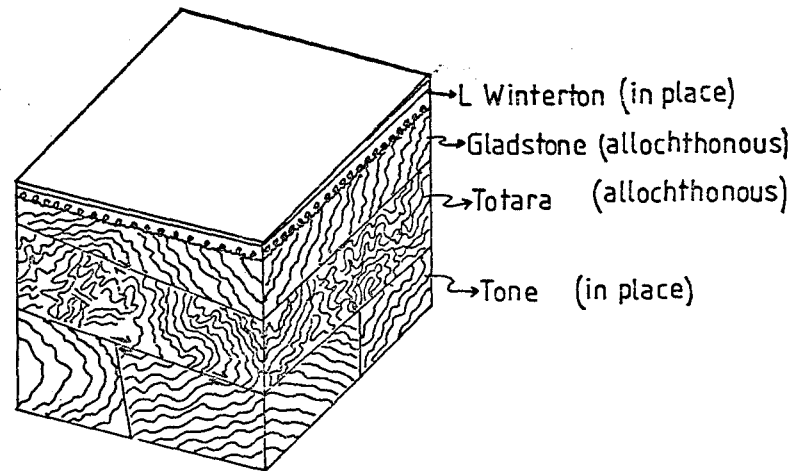
6.2a Tone Fm structure



6.2b Totara Fm structure



6.2c  
simplified structure Winterton R.



complete and the distinction between Torlesse and post Torlesse units on structural grounds is much less clear.

#### a) The Structure of the Totara Fm

The Totara Fm has a limited exposure in areas where it can be mapped with certainty; however, on virtually any scale the Totara Fm is more deformed than the Tone Fm. The abundance of small tight folds, the plastic pull-apart structures, and the disoriented sandstone blocks surrounded by mud rich rock (see fig 2.6) are characteristic features of Totara deformation.

In fig 6.2b a simplified view of Totara deformation is shown with the Totara Fm in gravity-tectonic slide contact with the Tone Fm. There is clearly no decrease in deformation upwards, in fact, the opposite is true. Totara-like units crop out at other localities in Marlborough (Penk Str. and Ouse Str.) and Wairarapa (Pahaoa Gp, Moore and Speden, 1979); this style of deformation is therefore widespread and in the Mt. Lookout outlier is distinct from the Tone Fm structural style. The tectonic significance of the structural difference between the Tone Fm and the Totara Fm is uncertain because the Totara Fm is lithologically, compositionally, and metamorphically similar to the Tone Fm.

#### b) The Structure of the Gladstone Fm

The Gladstone Fm, where allochthonous, is well indurated, broadly folded, has a local cleavage, and so strongly resembles the Tone Fm that Gair (1967) mapped the rocks as Torlesse greywacke. The intense deformation of the Gladstone Fm is interpreted as primarily due to the gravity-tectonic sliding of the unit. In Kicking Horse Cr. the Gladstone Fm is in place

and noticeably less deformed than the underlying Torlesse-like rocks, but there is not a noticeable difference in induration.

In fig 6.2c a simplified structural view of the Gladstone Fm is shown in relation to the structure of surrounding units. The Totara and Gladstone Formations both have deformation apparently related to gravity-tectonic sliding of the unit. One interpretation is that the Totara Fm is the more deformed lower section of a larger tectonic slide the top of which is the Gladstone Fm. However the Gladstone Fm also depositionally overlies the Totara Fm, so most of the deformation of the Totara Fm appears to have occurred before the deposition of the Gladstone Fm.

### c) Discussion

Figure 6.2c illustrates the problem in distinguishing Torlesse and post Torlesse rocks in the Winterton River area. The Totara Fm is Torlesse-like in degree of deformation, lithology, composition, and metamorphic rank; there is, however, a difference in structure style between it and the Tone Fm. Does this mean that there was a significant regional tectonic regime change between the Tone Fm and Totara Fm?

The Gladstone Fm appears to be a similar structural unit to the Totara Fm, although less severely deformed. The Gladstone Fm is Torlesse-like in its local degree of deformation, lithology, composition, and metamorphic rank; there is, however a marked decrease in deformation intensity from both the Totara and Tone Fms to the Gladstone Fm; does this indicate a regional change in tectonic regime?

If one uses the criteria of Laird (1980) that the regional unconformity is recognized by a marked decrease in deformation

and induration, the most obvious place for the regional unconformity would lie between the Gladstone Fm and the Lower Winterton Fm (fig 6.2c), but clearly the Gladstone Fm and Lower Winterton Fm are so alike in sedimentary style, lithology, composition and metamorphic rank that a major change in tectonic regime is unlikely.

Thus, I do not think structural changes alone can convincingly demonstrate the presence or absence of a regional unconformity in the Winterton River area. In the George River, there is a marked decrease in deformation between Torlesse-like and overlying strata; the unconformity marks a break in sedimentation caused by deformation and erosion before sedimentation was re-established. Does this necessarily mean that there is a change in tectonic regime? In continental areas, prominent angular unconformities do suggest regional changes in tectonic regime because such unconformities also contain a) large breaks in time (example: the Twins Mountain Fm, Lk, on Llano, PE, Granites, U.S.A.), and b) prominent changes in metamorphic rank (example: Grand Canyon Series on Vishnu Schist). On active continental margins, particularly convergent margins where fore-arc basin strata rest discordantly on newly deformed rocks (Seely 1979), angular unconformities may mark local tectonic changes without a change in a regional regime. Indeed, one of the aspects of active continental margins is that one would expect to see deformational styles migrate over time. Thus, I do not think that prominent angular unconformities alone suggest a change in the regional tectonic regime - it is the temporal and lithological changes which accompany the angular discordance which determine the tectonic significance.

## MOTUAN - NGATERIAN STRUCTURES

Post Gladstone Fm, pre Lookout Fm faults of known orientation are shown in figure 6.3; in the general cross sections other active faults during the Clarence Series are inferred.

One of these Clarence aged faults, the Totara Fault, is difficult to explain because although the base of the Lower Winterton Fm appears displaced, the underlying base of the Gladstone Fm does not appear displaced (see map 1 and general cross section C-C'). There is, however, an important structural discontinuity in the Gladstone Fm across the Totara Fault: the rocks on the NE side are in place but are allochthonous on the SW side of the fault. The apparent lack of displacement at the base of the Gladstone Fm can be resolved either by reversing the throw on the Totara Fault or by sliding the Totara Fm in with the Gladstone Fm (see fig 6.4). There is insufficient evidence to discriminate between these alternatives.

In the area between Middelhurst Cr and the George River there are three faults which show pre Lookout Fm displacements. These faults appear normal and have an orientation roughly E-NE. The Totara Fm has a northwest-southeast orientation similar to the Seymour fault in the Clarence valley which travels north-northwest (Reay 1980).

In fig 6.3 the known Clarence aged faults lie at orientations which are subparallel to the trend of the dyke swarm; this suggests that either the dyke swarm intruded along pre-existing faults and fractures or that the stress regime was the same during the Motuan and Ngaterian. Nicol (1977) interprets the dyke swarm as a radial development associated



fig 6.4 possible solutions of the Totara fault

## fault model



phase I: Gladstone Fm (autochthonous section) faulted and eroded



phase II: Gladstone Fm (allochthonous section) slides over the autochthonous section

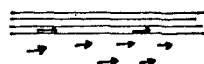


phase III: reverse movement on the fault and erosion



phase IV: resumption of sedimentation and normal fault movement

## Slide model



phase I: Gladstone Fm deposited on Totara Fm; Totara Fm begins to slide



phase II: part of the Gladstone slides with the Totara Fm; sliding in the Totara Fm causes thickening and thinning



phase III: end of sliding, erosion begins



phase IV: sedimentation re-established, faulting between the autochthonous and allochthonous sections of the Gladstone Fm

with cone sheets around the Tapuaenuku igneous centre. The cone sheets intrude the Tapuaenuku Plutonic Complex (Nicol 1977), suggesting that the dyke swarm formed after the layered intrusive. There is also evidence that the dyke swarm is a regional feature rather than a local radial swarm. Grape's (1975) map of the Blue Mt. Igneous Complex shows that the dyke swarm cuts across the intrusion along two preferred directions (NNE and E-W). Map 3 shows that Cretaceous dykes are widespread throughout the Inland Kaikoura Range and appear to have a strong NNE and E-W trend. Scattered dykes also appear with a NE orientation in Ouse Stream (pers. observations) and in the Seaward Kaikoura Range around Manakau (S. Weaver, J. Bradshaw pers.comm.). Thus the regional distribution of the dykes and the preferred directions of intrusion suggest that the dykes may have intruded along a conjugate set of fractures.

#### KAIKOURA DEFORMATION

The present structure of the outlier is controlled by Kaikoura movements and specifically by the Awatere Fault. Generally the outlier forms a large syncline whose NW limb is cut by the Awatere fault and associated minor faults.

Folding is subordinate to faulting and tilting; figure 6.6 shows how most of the outlier is tilted to the N.W. Apart from the overall synform of the outlier, the only large scale folds lie in the Awatere River-Winterton River area. In the region around Gladstone Cr. there is a syncline which is broad and plunges gently to the southwest; both limbs are cut by northeast-southwest trending faults. Just across the Old Middelhurst Fault (see map 1 and general cross section B-B') is another broad syncline which also plunges southwest.



The anticline between these two synclines is not well developed and may be replaced by the Old Middelhurst Fault.

On map 1, where the Old Middelhurst Fault crosses the Winterton River (S35/450,850), the Gladstone Fm crops out on the northeast side of the river but is absent on the southwest side. The missing contact between the Gladstone Fm and the Lower Winterton Fm is presumed to lie beneath the river gravels and may be a sedimentary contact or a fault.

Faults cut the outlier with increasing intensity towards the Awatere Fault and break the outlier up into tilted blocks (see map 1 and general cross sections). In the Winterton River area faults generally are downthrown to the northwest but are upthrown to the NW in the Middelhurst Creek area. This makes the faults difficult to correlate through the volcanic pile. The apparent reversal in fault displacement from the northeast to the southwest part of the outlier may be explained by normal faults which have a scissor-like movement. However this explanation would require a change in the fault plane orientation and such a change is hard to prove in the volcanic pile where the faults are difficult to map. A simpler explanation would be that the faults have lateral displacements, which in a doubly plunging syncline, would cause an apparent reversal of displacement across the structure (see fig 6.5).

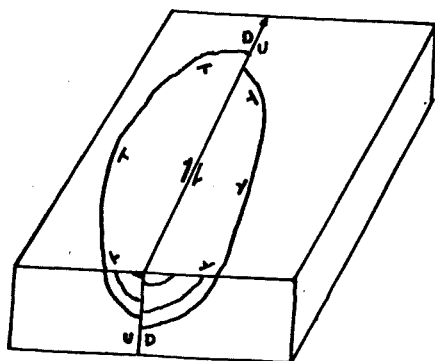


fig 6.5  
the effect of a strike slip fault  
on a doubly plunging structure

The number of faults increases towards the Awatere Fault and faults close to the Awatere Fault are steep, which may suggest strike slip movement. The Awatere Fault itself is linear and almost vertical. The rocks close to the Awatere Fault are progressively deformed into a pseudo melange. Thus, the Awatere Fault is structurally more of a zone than a single plane. The most striking deformation fabric in the fault zone is the brittle fractures which break the rock up severely. Some of these brittle fractures are annealed and filled with carbonate, quartz, or zeolite? while others are open; these features suggest the Awatere Fault has moved sporadically. The Greywacke A (Challis 1966) rocks on the northwest side of the fault are distinct from the Tone Fm in being muddier, containing interbedded spilites and red chert, and being prehnite-pumpellyite facies (Challis 1966). The juxtaposition of low zeolite facies rocks (the Tone Fm) with prehnite-pumpellyite grade rocks (Greywacke A) suggests that either the Awatere Fault has moved several kilometers in a vertical direction upthrown to the northwest or that extensive lateral displacement has brought Greywacke A rocks in contact with the Tone Fm. Since the Awatere Fault is believed to be part of the Alpine Fault system and since the Alpine fault has moved over 400 km, the second alternative for the origin of Greywacke A rocks appears more reasonable.

## CHAPTER 7

## PART 1 : REGIONAL CORRELATIONS

MIDDLE AWATERE VALLEY

Map 3 contains a simplified map of the Middle Awatere area taken from Allen (1962), personal observations, and discussion with M. Laird. Penk Stream has the best exposure and contains a basal 240 m olistostrome, overlain by clast supported, muddy matrix, boulder to pebble conglomerates which pass up into a 350 m flysch-like sequence (Laird 1980a). The flysch-like unit suddenly changes to a massive mudstone 150 m<sup>+</sup> thick; the contact is sharp and some disruption appears in the flysch-like beds near the contact. The mudstone contact may be either a fault or an unconformity (without discordance). The basal olistostrome and flysch-like sequence have been dated as no older than Motuan on the presence of Aucellina eughypha in limestone clasts; the overlying mudstone has been dated Ngaterian on the presence of Inoceramus sp ex gr fufre-hakarius. The basal olistostrome unconformably overlies a strongly deformed unit, similar to the Totara Fm. This strongly deformed unit was previously mapped by Allen (1962) as greywacke B, but I consider it a separate unit. The thick sandstones which characterize the Tone Fm can be seen to the south and southwest of Awapiri Station (fig 7.1). The contact between the Tone Fm and the Totara-like unit lies in the Awapiri-Bolton area. The Lookout Fm lies on the truncated Ngaterian mudstone southwest of Penk Str. and unconformably overlies the flysch-like unit near the mouth of the Hodder River.

Fig. 7.1

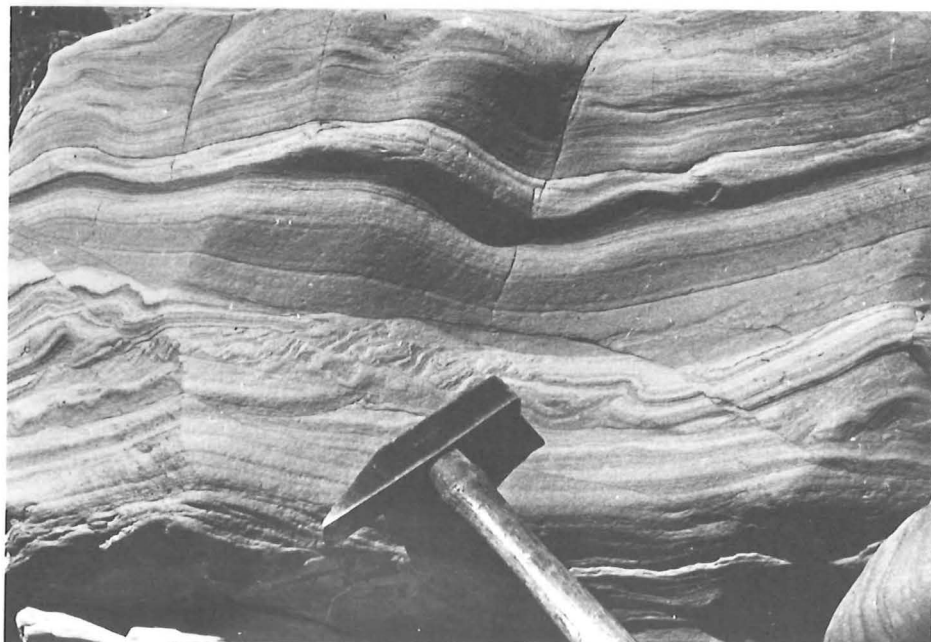
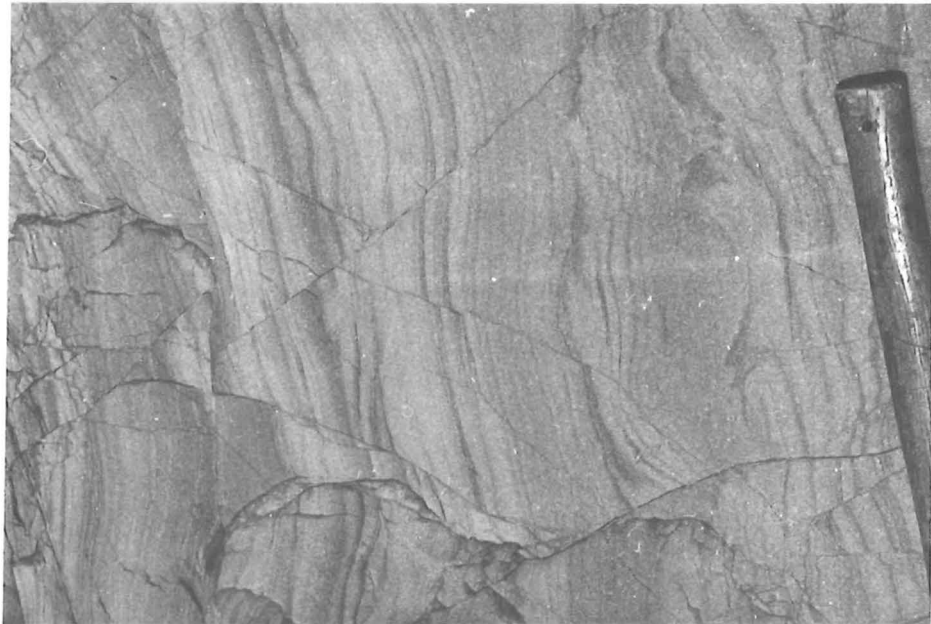
Thick sandstones of the Tone Fm forming ridges behind (SE) Awapiri Station; Mt. Tapuaenuku is on the far left.

Fig. 7.4

Pikes Fm sandstone; note the annealed micro faults are similar to Fig. 5.16.

Fig. 7.5

Wharfe Fm sandstone; note internal deformation and abundance of parallel lamination, similar to 7.4.



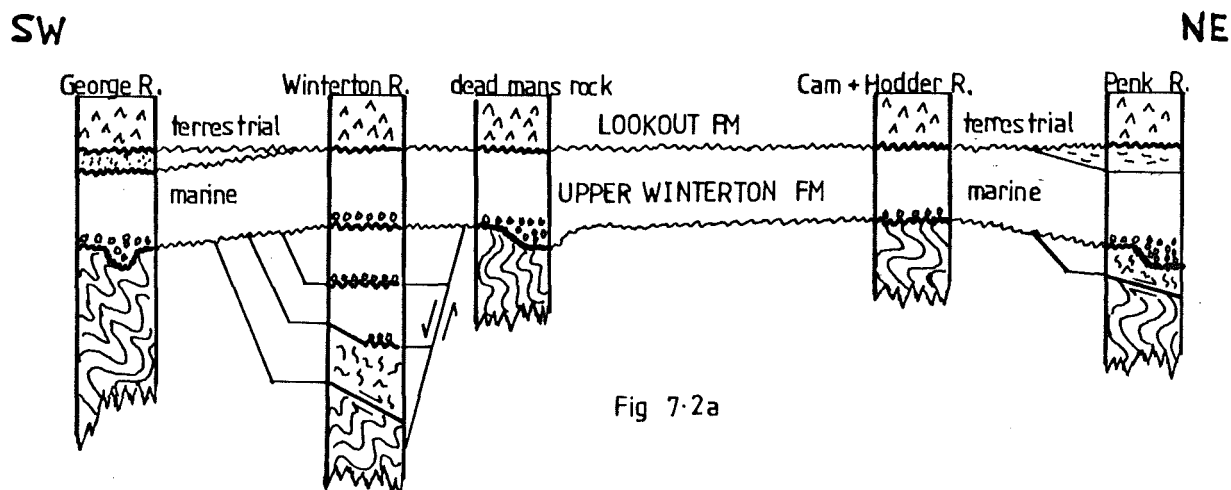
The olistostrome and flysch-like unit have been interpreted either as a submarine channel fill and subsequent submarine fan deposits or as a proximal fan channel-interchannel sequence (Laird 1980a). The thick, channel like geometry of the olistostrome and conglomerates, the suggestion of a fining upwards sequence, the similar paleocurrent direction (SW→ NE), and Motuan age suggest, the Penk Str. sequence is the downdip correlative of the Upper Winterton Fm. Correlation to the Lower Winterton Fm is possible, but the Upper Winterton Fm has a deeper, better developed basal channel, which would be more likely to feed an olistostrome.

The Penk R. Ngaterian mudstone may be the correlative of either the Castle Creek Conglomerate or the Lookout Fm coal measures. Since the coal measures appear to reflect quiet sedimentation and are believed to be Ngaterian, the Penk R. mudstone is possibly the down dip correlative. However, the overall thickness of the Penk R. mudstone suggests that the Castle Creek Conglomerate (which is not fully preserved) may be a coarse facies equivalent. A third alternative is that, being more basinward, the Penk R. area was not affected by the disturbances which affected the Mt. Lookout area. Thus the movements which caused the unconformities which underlie and overlie the Castle Creek Conglomerate may have no correlatives in the Middle Awatere valley. The Penk R. mudstone may thus be correlative with both the Castle Creek Conglomerate and the Lookout Fm coal measures.

The lower Penk R. highly deformed and disrupted unit is similar to the Totara Fm in structural (or destructional)

style and lithology. These two units may have formed at the same time or at different times by the same mechanism.

In summary the preferred correlations between the Middle Awatere and Mt. Lookout areas are shown in fig 7.2.



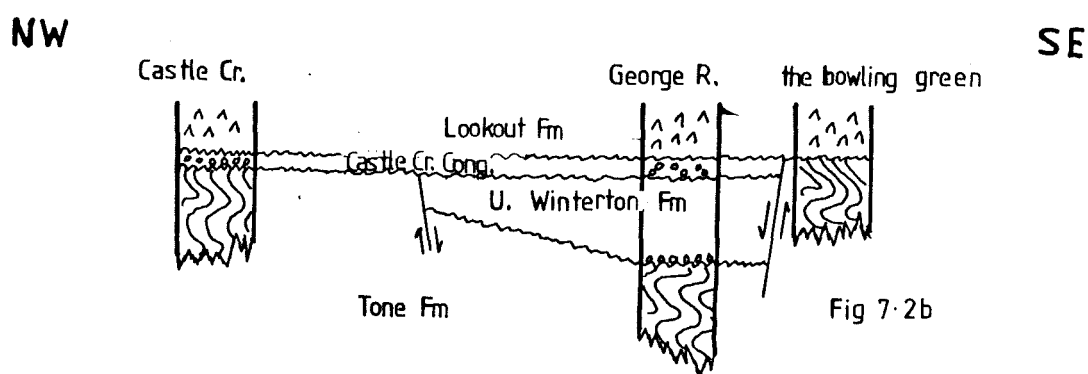
Although the Middle Awatere area lies down paleo-dip from the Mt. Lookout area, the overall post-Tone Fm section is thinner than up-dip in the Winterton River. Generally, the further basinward section will contain a more complete sedimentation record; the Middle Awatere area, however, has less of a preserved record and a thinner record than the Mt. Lookout area. This indicates that although the Middle Awatere section is down dip, it also represents a localized basin fill. This hypothesis is supported by the general discontinuity of units in the Middle Awatere (compare the Cam-Hodder section with Penk R). The Penk R. mudstone is also overlain by terrestrial lava flows of the same age; although the contact is an unconformity, the structural discordance is not great and suggests that the Middle Awatere succession was not deposited in especially deep water.

The correlations shown in fig 7.2 bring out two important features: 1) the widespread unconformity between the

terrestrial( Lookout Fm) lava flows and the marine, flysch-like sequences; and 2) the continuous preservation of the U. Winterton relative to other units.

The unconformity separating the Lookout Fm lavas from the marine sequences appears to represent a significant geologic event in the Awatere region. It is not known for certain whether this Ngaterian unconformity represents a separate tectonic regime or the continuation of a Motuan regime. The presence of an alkaline volcanic source in the provenance of the sandstones and conglomerates and the evidence which indicates that the Tapuaenuku and Blue Mt. complexes formed prior to the dyke swarm suggests that volcanism in the inland Kaikouras was established by the Motuan and climaxed with the intrusion of the dyke swarm in the Ngaterian. Thus, no major tectonic change is indicated by the sub regional, Ngaterian unconformity.

The Upper Winterton appears more widespread than any of the other marine, flysch-like units. This may be due to more favourable preservation or because tectonic conditions allowed (for the first time) a unit to transgress most of the area. What is particularly interesting about the distribution of the Upper Winterton is the great continuity down the Awatere Valley and its limited preservation across the Awatere Valley (compare figs 7.2a and 7.2b).





Thus, the pre Lookout Fm preservation of the Upper Winterton Fm is elongate in a SW to NE direction; this suggests that either original deposition may have been in a SW to NE linear basin, or that Ngaterian tectonic activity caused preservation in an elongate SW-NE orientation.

In summary, the units which correlate from Mt. Lookout to the Middle Awatere Valley are the Lookout Fm, Upper Winterton Fm, and the Tone Fm. The overall thinness of the Middle Awatere section and the discontinuity of stratigraphic units between the Penk and Cam-Hodder Rivers suggests a basin in the Middle Awatere similar to the Mt. Lookout basin with a high in-between. The presence of terrestrial volcanics unconformably overlying mildly deformed marine sequences of similar age suggests the Middle Awatere area was also proximal to the shoreline, although down paleocurrent from Mt. Lookout.

#### MIDDLE CLARENCE VALLEY

Map 3 shows a simplified geology of the Middle Clarence outliers (after Lensen 1962 and Reay 1980) and three stratigraphic columns (after Reay 1980). The Split Rock Fm is a Motuan, marine, fining upward unit containing a thin (24 m thick) basal conglomerate overlain by a flysch-like sequence which may be overlain by a siltstone unit (Reay 1980). The Split Rock Fm is poorly preserved and the Motuan age makes it a correlative of the Upper Winterton Fm, Lower Winterton Fm, or Gladstone Fm. The Middle Clarence outliers contain evidence for pre Gridiron Fm faulting, causing erosion of the Split Rock Fm and subsequent deposition of the Gridiron Fm on Torlesse basement (Reay, 1980). This supports

the conclusion drawn from the Mt. Lookout area that periods of sedimentation were broken by faulting and erosion. The paleoenvironmental interpretation for the Split Rock Fm was shelf or near shelf by Reay (1980) and shelf by Lensen (in Suggate et al 1978). This platform-like environment is similar to the one envisioned for the Mt. Lookout and Middle Awatere Motuan rocks.

While the Split Rock Fm is similar to the units at Mt. Lookout in lithology, sandstone provenance (personal observations of thin sections), depositional environment, and perhaps as a fining upward sequence, there is nothing to tie the Split Rock Fm specifically to either the Castle Creek Conglomerate or the Upper Winterton Fm, or the Lower Winterton Fm or the Gladstone Fm. Alternatively, the Split Rock Fm may represent a basin fill not continuous with any units in the Awatere Valley.

The problem of correlating the Split Rock Fm to the Mt. Lookout area reflects on the relationship between the Torlesse-like basement and the unconformably overlying Motuan rocks. Although the break between these two rock units is termed a "regional unconformity" the dating of the unconformity between the Split Rock Fm and the Torlesse and the unconformity separating the Castle Creek Conglomerate, Upper Winterton, or Gladstone Fm from the Tone Fm is insufficiently accurate for correlation. Indeed, the geological interpretations of both the Mt. Lookout and Middle Clarence areas (i.e., periods of sedimentation broken by tectonism and erosion) almost precludes the possibility that any of the Torlesse/overmass unconformities are continuous over a long distance.

The Gridiron Fm (Cn) is composed of basal coal measures, a sequence of alkaline basalts, and an overlying terrestrial and/or marine sequence (Reay 1980). The basalt flows are geochemically related to the Lookout basalts (Nicol 1977), and the Warder Coal Measures (Reay 1980) appear to be equivalent to the basal Lookout coal measures, although the environment of deposition is slightly different. The Gridiron Fm, like the Lookout Fm, unconformably overlies marine, flysch-like Motuan and Torlesse rocks. The apparent ease of correlation of the Gridiron Fm and Lookout Fm and their sub units suggests more widespread conditions in the Ngaterian than the Motuan. The unconformity between the Ngaterian volcanic units and older rocks appears to be also widespread, from the Middle and Upper Awatere to the Middle Clarence valley; it is unlikely, however, that this is an isochronous surface.

In summary, the geologic history of the Mt. Lookout and Middle Clarence areas are similar during the Motuan and Ngaterian. During the Motuan marine, flysch-like sedimentation is interrupted by faulting and subsequent erosion. However, the two areas are thought to have developed independently. In the Ngaterian a widespread igneous event may have caused continuous deposition from the Clarence to the Awatere valley; this is suggested by the great similarity between the Gridiron Fm and the Lookout Fm. In both the Motuan and Ngaterian rocks, however, the dating is too inaccurate to correlate unconformities.

## COVERHAM

Few areas are more controversial than Coverham, particularly the Ouse Stream section (fig 7.3). Lensen (1962, in Suggate et al 1978) proposed that the Ouse Siltstone conformably overlies the Pikes Fm. Hall (in press) felt the contact was disconformable. Gair (1967) and Speden (1978) felt the contact was discordant, as Speden (in Stevens and Speden 1978) writes:

"The boundary separates rocks differing markedly in degree of structural complexity, environment of deposition, and, to a lesser degree, induration. It coincides with a major stratigraphic change of uncertain tectonic and time significance, but is similar to the intra-Motuan change in parts of the Raukumara Peninsula and Wairarapa."

The Ouse Str. was traversed by myself and Dr Bradshaw from Coverham Station to S35/128, 435. The Ouse Siltstone becomes increasingly disturbed down section with small recumbent folds and many small offsets. The contact of the Ouse Siltstone on the Pikes Fm (Hall 1964) (fig 7.3) is picked by Hall (1964), Gair (1967), and Speden (1977) at the base of a 5-8 m pebbly conglomerate. Below the conglomerate is about 30 m of interbedded thick sandstones and thin mudstones. Hall (in press) and Gair (1967) describe these thick bedded sandstones as poorly sorted, graded, greywackes; to me, the thick bedded sandstones appeared well sorted, parallel laminated, moderately well to well indurated, and identical to sandstones in the Wharfe Fm (see figs 7.4 & 7.5). The thick bedded sandstones were boudinaged, full of small offsets, and steeply dipping but did not appear greatly more deformed or indurated than the base of the Ouse Fm. The conglomerate overlying the thick

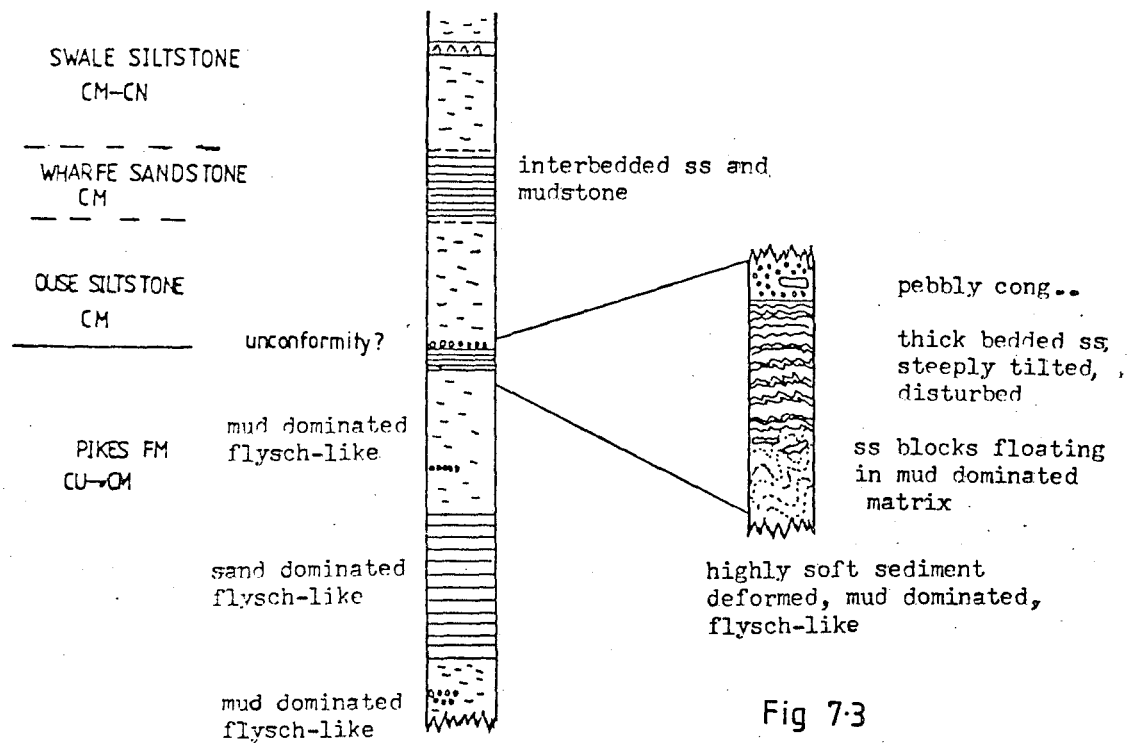
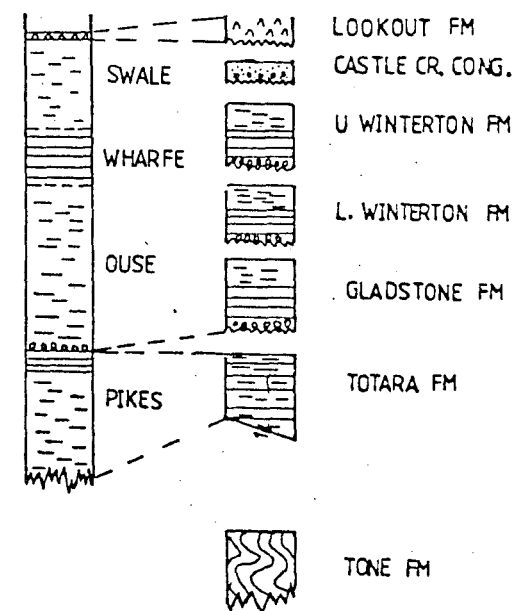


Fig 7-3

CORRELATION OF OUSE STR. SECTION  
AND MT. LOOKOUT



sandstones contains 90% moderately indurated (cannibalized) sedimentary, pebble sized clasts and about 10% well rounded and indurated Torlesse clasts. This suggests localized erosion. The pebbly conglomerate appears to have rafts of the thick bedded sandstones floating in it. The pebbly conglomerate does appear to represent an erosional period separating the thick sandstones from the Ouse Siltstone.

The thick bedded sandstones overlie (discordantly?) a thick sequence of mudstone dominated, thin bedded, alternating sandstones, siltstones and mudstones which are highly contorted, disrupted, tightly asymmetrically folded, boudinaged, and have no consistent strike (like the Totara Fm). The thick bedded sandstones are highly disrupted near the transition to the mud dominated unit and big blocks of thick sandstone may float in a mud rich matrix. About .7 miles down Ouse Str. from the Ouse Fm contact, the mud rich Pikes Fm suddenly changes into a sand dominated flysch-like unit with a similar structural pattern. A conglomerate of possible importance is present near the contact. Further downstream at S35/130, 436 the sand rich unit sharply changes back into a mud dominated unit.

The significance of the Ouse Fm/Pikes Fm contact has been hotly debated. Gair (1967) and, indirectly, Laird (1980) have suggested the contact is a unconformity separating rocks of two tectonic regimes.

The deformational style of the Pikes Fm is similar to that of the Totara Fm, the unit below the Penk Str. Olistostrome, and the published descriptions of the Pahaoa Gp (Moore and Speden 1979) in Wairarapa. The asymmetry of the folds, the tight discontinuous nature of the folds, the

lack of any persistent cleavage, the numerous discontinuous offsets, and the sand and mud injection and flowage structures indicate that deformation occurred before lithification. Thin section analysis showed that the sandstones of both the Pikes Fm and Wharfe Fm are feldspathic, lithic arenites whose lithic component is dominated by igneous clasts. These clasts include partially altered basalts, chert-like, feldspathic volcanic clasts, and unweathered trachyte. Thus, sandstone compositions from the Pikes Fm and Wharfe Fm are also very similar to the Split Rock Fm (determined by personal observations of Split Rock thin sections) and the Middelhurst succession. Both the Pikes Fm and Wharfe Fm contained alteration zeolites (natrolite family) and both units have a complicated diagenetic history of solution and feldspar overgrowths. No evidence for a metamorphic break was discovered. About .4 miles down from Ouse Fm contact, a dyke, similar to the dyke swarm of the Inland Kaikoura Range, intrudes the Pikes Fm. The contact is undulatory, irregular and does not fill a clearly defined extension fracture. The margins suggest that the Pikes Fm was not fully lithified at the time of intrusion. Since the dyke swarm post-dates the Ouse Fm, the Pikes Fm could not have been well indurated during the deposition of the Ouse Fm and this supports the thin section evidence that there is no metamorphic break between the two units. The Pikes Fm sandstones contain well preserved sedimentary structures, mostly parallel lamination with some cross lamination and ripples. This style of structures closely resembles the sandstones in the Wharfe Fm and Ouse Fm. The Pikes Fm is less fossiliferous, but this may be due to post depositional

disruption; the fauna in the Ouse Fm itself appears to be redeposited, so the degree of fossil abundance may be due to the availability of a source of fossils. Thus, while one may conclude that the Ouse Fm is closer to the shoreline, there is no lithological or sedimentological evidence to suggest a major change in depositional environment from the Pikes Fm to the Ouse Fm.

Thus, the Pikes Fm has a similar age, Urutawan-Motuan (Speden 1977), similar lithology (dominantly muds and silts), similar sandstone compositions, provenance, and a similar offshore marine environment to the overlying Ouse Fm. Thin section work supports field evidence that there is no metamorphic break between the two units. There is a decrease in degree of deformation across the contact, but the Ouse Fm itself is disrupted increasingly near the base, suggesting continued instability. Therefore the evidence appears to indicate that the Pikes Fm and Ouse Fm are related units rather than representing a major change in tectonic regime.

The Coverham section does not correlate especially well to the Mt. Lookout area. The Pikes Fm is similar lithologically, compositionally, and structurally to the Totara Fm, but dating is not sufficiently accurate to correlate the two units. The Ouse Fm and Wharfe Fm have equivalent ages to the Gladstone Fm, Lower Winterton Fm, and Upper Winterton Fm, but the rocks at Coverham are more fine grained and depositional cycles are less apparent. The Wharfe Fm sandstones have a similar composition and provenance as the Mt. Lookout rocks, but are slightly more quartzose. Perhaps the greatest difference is the continuous sedimentation at Coverham from the Motuan through the



Ngaterian. The igneous event which affects the Awatere Valley and Middle Clarence Valley is present only as a thin body of pillow lavas in the Swale Fm (in Swale Str, Gair 1967, J. Bradshaw pers. comm.). The Ouse Fm, Wharfe Fm, and Swale Fm are missing in Big Slip Gulley (one mile east of Ouse Str) where Raukumara age rocks rest unconformably on the Pikes Fm. Hall's (1964) map suggests that these Upper Clarence units were faulted and eroded away prior to the deposition of the Burnt Creek Fm. This indicates that tectonic movements were interrupting sedimentation in a similar way at Coverham as at Mt. Lookout.

#### WAIMA RIVER

Gair (1967) traversed Blue Mountain stream and found a Torlesse-like succession containing fossiliferous pebbles with Motuan fossils (Aucellina euglypha Woods) and Jurassic fossils (Anopaea n.sp, Buchia Aff subpallasi). The unit is at least partly Motuan or younger. To the east, Prebble (1976) described a Torlesse-like greywacke in which Inoceramus c.f. concentricus and Aucellina euglypha were found in Flags Cr. and Aucellina euglypha and Inoceramus sp indet. in Dunsandel Str., indicating a Motuan age for at least part of these greywacke units. The similarity in age between these Torlesse-like rocks and the moderately or mildly deformed Motuan rocks around Mt. Lookout suggests that the rocks in the Waima River area may have been deformed before, during, or after the deposition of covering strata at Mt. Lookout. Thus, the fossil dates do not prove that all covering strata are younger than the underlying more deformed, Torlesse-like rocks.

SEAWARD KAIKOURAS

Near the mouth of the Clarence R., two Motuan, flysch-like units crop out. The thinner unit at Waipapa Bay consists of a basal 15 m of pebbly mudstone followed by interformational breccias and about 100 m of flysch-like sandstones and mudstones (M. Laird pers.comm.). This sequence is repeated in Wharekiri Str., but the succession is much thicker (M. Laird pers.comm.). The age, lithologies, and fining upward character resembles the cyclic units at Mt. Lookout. The presence of a thin basal conglomerate at Waipapa Bay and a thick basal conglomerate in Wharekiri Str. suggests the conglomerate unit is draped over highs; the thickness changes over the short distance between Waipapa Bay and Wharekiri Str. may be aided by active faulting during deposition. The paleocurrent direction of the Wharekiri Str. section is approximately SW-NE (M. Laird pers.comm.), a similar orientation to the Middelhurst succession and similar in part to the Wharfe Fm (Hall in press). At Waipapa Bay, the sequence passes up conformably into Ngaterian sediments; no volcanic horizons are reported (M. Laird pers.comm.).

A Ngaterian deltaic sequence is exposed in the Hapuku River which unfortunately is fault bounded so no older Clarence rocks are exposed (M. Laird pers.comm.). A sharp contact occurs between the deltaic unit and a mud dominated Ngaterian to Raukumara unit; this surface may represent a hiatus (M. Laird pers.comm.). Again, there are no reported volcanic horizons. The deltaic unit may be correlative with the Warder Coal Measures in the Middle Clarence Valley (Reay 1980) and the Lookout coal measures.

## DISCUSSION

Summarizing this review, there are some general features about the regional picture which help to interpret the succession at Mt. Lookout:

1. Rocks potentially down dip but the same age as the Mt. Lookout Motuan rocks were apparently being deformed during or shortly after Mt. Lookout sedimentation. This supports the suggestion that the Mt. Lookout cycles reflect ongoing tectonism.
2. Motuan or post Motuan pre Raukumara faulting is apparent in the Middle Clarence and Coverham successions. This supports the evidence in the Mt. Lookout area of alternating periods of deposition, tectonism, and erosion.
3. The occurrence of Motuan aged sequences with conglomeratic bases grading up into flysch-like sequences is present at Mt. Lookout, the Middle Awatere, the Middle Clarence Valley, and the lower Clarence Valley. The regional distribution of this style of sedimentation suggests a tectonic control rather than control by a sedimentary system.
4. Compositional differences between rocks in the Awatere and Clarence Valleys are mild and suggest similar but separate basins.
5. The western part of Marlborough was strongly affected by a Ngaterian igneous episode, while the eastern area remained relatively quiet.
6. Other sections in Marlborough suggest that Totara-like units are widespread and represent ongoing

tectonism and sedimentation up into the Motuan; the Totara-like units appear genetically related to units which unconformably overlies them.

7. The Clarence aged rocks around Marlborough are sufficiently different and the dating is sufficiently crude to eliminate any reliability in correlating unconformable surfaces separating Torlesse-like and post Torlesse rocks.

## CHAPTER 8: SYNTHESIS

EVALUATION OF THE CONCEPT OF A REGIONAL UNCONFORMITY.

For a long time, geologists have recognized a difference between late Cretaceous (Mata) rocks and Torlesse rocks. The whole concept of a "regional unconformity" is an attempt to tie this change down to a specific time. In a Stillian way, to say: before this time - Torlesse conditions, after this time - post Torlesse conditions. Properly defined, a regional unconformity is an "unconformity continuously present throughout an extensive region recording an important interruption in sedimentary deposition and generally erosion of older strata" (AGI DICTIONARY). Applied to the New Zealand Lower Cretaceous, a regional unconformity would have to extend over all of Marlborough and probably Wairarapa and Raukumara as well.

The evidence most cited by geologists as indicating a regional unconformity is : 1) a significant time break across the unconformity such that rocks above the unconformity are everywhere younger than rocks below it, 2) a significant decrease in deformation and or structural style, 3) a decrease in induration and metamorphic rank, and 4) a significant change in depositional environment.

1. Is There A Time Break?

Looking at Lower Cretaceous rocks in Marlborough as a whole, previous interpretations of the regional unconformity have regarded highly deformed rocks as Torlesse and mildly deformed rocks as "overmass" or post Torlesse (Gair 1967,

Speden 1978, Laird 1980). The fossil dating, however, is not sufficiently accurate to conclude that all highly deformed rocks are everywhere older than the oldest covering strata; on the contrary, the rocks appear to have similar ages. Speden (in Stevens and Speden 1978) and Moore and Speden (1979) recognized this and proposed that a major intra-Motuan event marked by a regional unconformity occurred over much of New Zealand. It is true that in areas where highly deformed, Motuan to Urutawan aged rocks are overlain unconformably by significantly less deformed Motuan aged rocks that a prominent unconformity exists. However, what about those Torlesse-like rocks dated Motuan or Albian which do not have overlying Motuan or Albian strata? The accuracy of the dating allows these rocks to have been deformed during or after deposition of covering strata. Indeed, the restricted nature of Motuan age covering strata in Marlborough suggests that deformation and sedimentation are contemporaneous. Thus, one of the key pieces of evidence for a regional Albian unconformity in Marlborough (i.e. that the covering strata are everywhere younger than the Torlesse-like strata) is not demonstrable.

## 2. The Regional Unconformity At Mt. Lookout

Since the age of covering strata and some of the Torlesse-like strata are the same, I will try to apply the other lines of evidence to the Mt. Lookout outlier and see whether the regional unconformity can convincingly be demonstrated.

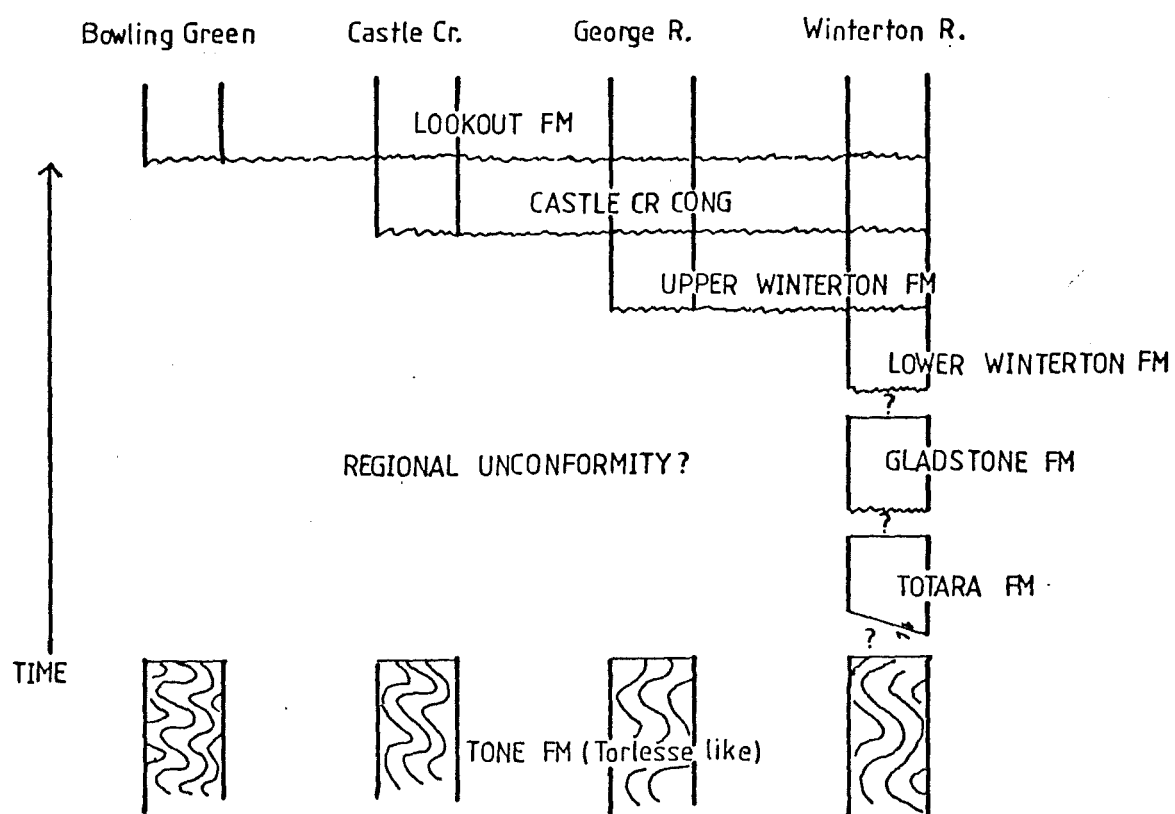
In the southwestern part of the Mt. Lookout outlier (i.e. Castle Cr, George R., the Bowling Green) there is a

marked decrease in induration and structural complexity between Torlesse (Tone Fm) rocks and overlying Motuan and Ngaterian rocks (fig 8.1). This unconformity would be the most likely candidate for a major tectonic-stratigraphic break. The age of the erosion surface which physically embodies the unconformity is not, however, the same age in each of the southwestern sections (fig 8.1). The time break represented by the unconformity is not known.

Although the structural and induration differences between the Tone Fm and overlying rocks are sharp, the Motuan covering strata and Torlesse rocks have many similarities. Both rock groups are marine, flysch-like and contain sandstones of mass flow origin. The break in depositional environment is only a change from slope to platform, which may originate in a variety of ways besides a major tectonic change. Where the thermal overprint from the dyke swam is weak, there does not appear to be any significant metamorphic break between Torlesse-like and overlying rocks. Finally, the sandstones and mudstones of the Tone Fm and the overlying Motuan units have essentially identical compositions.

In the Winterton River area, where the stratigraphic record is more complete, the stratigraphic position of the regional unconformity is uncertain. As in the southwestern part of the outlier, the rocks overlying the Tone Fm are similar in depositional processes, detrital composition, and lithologies. The change in depositional environment also appears mild. There is no difference in induration or metamorphic rank between the Tone Fm and the Totara Fm or Gladstone Fm. This may in part be due to a metamorphic overprint; however, if low zeolite facies metamorphism is

FIG: 8.1





an overprint, then the original metamorphic differences must have been minimal.

Since the Torlesse-like and overlying rocks are lithologically, depositionally, compositionally, and metamorphically similar, a change in structure and/or a time break are the only features left to distinguish a major tectonic, stratigraphic break. From the southwest area of the outlier, one might surmise that the regional unconformity in the Winterton River lies directly above the Tone Fm. The unit overlying the Tone Fm is the Totara Fm; although these two units are structurally distinct, the Totara Fm in some respects is more severely deformed than the Tone Fm. This is in contrast with structural evidence of a regional unconformity in the George River, where there was a significant decrease in degree of deformation across the unconformity. So in the Winterton River, structural criteria would suggest that the regional unconformity lies above the Totara Fm: between the Totara Fm and the Gladstone Fm. These two units do have a marked angular discordance and there is a marked decrease in deformation across the contact. However, the Gladstone Fm is also deformed, and in some places is difficult to distinguish from the Tone Fm. Thus, it seems to me that there will always be controversy as to whether the Gladstone or Totara Fms belong to the Torlesse or the post Torlesse side of the regional unconformity. Faced with a similar situation, Moore and Speden (1979) placed a regional unconformity above their Totara-like unit (the Pahaoa Group). This solution does not solve the dilemma at Mt. Lookout, however, because the Gladstone contains structural aspects of both Torlesse-like and overlying strata.

Putting the regional unconformity above the Gladstone Fm does not help either because depositionally, the Gladstone Fm is the first of a series of sedimentary cycles. Thus, the significance of the Winterton River area is that there is no convincing stratigraphic position to fit the regional unconformity.

Similar problems in locating a major tectonic-stratigraphic break occur in Marlborough. At Coverham, the contact between the Ouse Fm and the Pikes Fm has been very controversial. The problem is that even if a convincing unconformity between the Ouse and Pikes Fms can be mapped out, there is enough lithologic, age, and, to a lesser extent, structural similarity between these two formations to suggest that they belong to the same orogenic cycle. The same can be said for the contact between the olistostrome and Totara-like rocks in Penk Stream.

In conclusion, the Lower Cretaceous section at Mt. Lookout does not show a clear distinction on lithologic, depositional, compositional, metamorphic, or structural grounds, of a major tectonic-stratigraphic break. Other areas in Marlborough, notably Coverham, have the same problem. This is exactly the sort of difficulty one would expect on a continental margin, where tectonism and sedimentation are simultaneous. Thus, I think it is fair to take the uncertainty in differentiating Torlesse and covering strata as an indication that the transition from Rangitata to post Rangitata conditions was evolutionary and probably contains features both of compression and extension. Thus, rather than try to pin the tectonic change to a specific position on the stratigraphic chart (i.e. the concept of a regional

unconformity) the stratigraphic nomenclature should acknowledge the evolutionary nature of the New Zealand Lower Cretaceous and abandon the concept of a regional unconformity.

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